

AD-A253 392

(2)

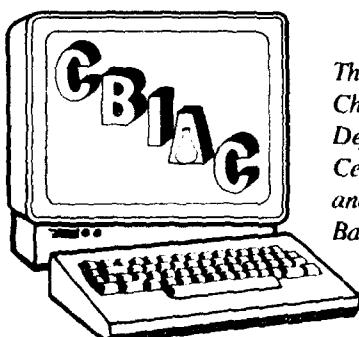
DTIC
ELECTED
JUL 23 1992
S C D

REPORT

Evaluation of Multi- Layer Mask Concept for Respo 21

To
U.S. Army Chemical Research,
Development and Engineering Center

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited



*The Chemical Warfare/
Chemical and Biological
Defense Information Analysis
Center is a DoD information
analysis center operated by
Battelle Memorial Institute*

DECEMBER 1991

92-19383



 **Battelle**
Putting Technology To Work

92 7 21 058

**THIS
PAGE
IS
MISSING
IN
ORIGINAL
DOCUMENT**

Pages 1, 3, 4, 5, 24, 33, 56, 93

FINAL REPORT

on

**EVALUATION OF MULTI-LAYER MASK CONCEPT
FOR RESPO 21**

to

**US ARMY CHEMICAL RESEARCH, DEVELOPMENT
AND ENGINEERING CENTER
Aberdeen Proving Ground, MD 21010**

December 1991

by

T. A. Pettenski

**BATTELLE
505 King Avenue
Columbus, Ohio 43201**

Accession For	
NTM	SRAB
Spec	<input type="checkbox"/>
Spec	<input type="checkbox"/>
Classification	
By	
Distribution/	
Availability Codes	
Avail	and/or
Dist	Special
R-1	

TABLE OF CONTENTS

	<u>Page</u>
1.0 BACKGROUND	1
1.1 Objective	1
1.2 Program Plan	1
2.0 DESIGN GOALS	2
3.0 REVIEW OF PREVIOUS WORK.....	2
4.0 DEFINE FUNCTIONAL CHARACTERISTICS	3
4.1 Facepiece	3
4.2 Faceseal	4
4.3 Lenses for Optical Corrections	4
4.4 Check Valves	4
4.5 Suspension	4
4.6 Hood	5
4.7 Filter Element	5
4.8 Communications.....	5
4.9 Blower	5
4.10 Power Supply	5
5.0 DESIGN	5
5.1 Preliminary Design	6
5.2 Facepiece	6
5.3 Optical Inserts	10
5.4 Laser Protection	12
5.5 Peripheral Faceseal	12
5.6 Hood	12

TABLE OF CONTENTS
(Continued)

	<u>Page</u>
5.7 Barrier Film	13
5.8 Filter	13
5.9 Electrical Components	14
5.9.1 Blower	14
5.9.2 Other Electrical Components	14
5.10 Critical Airflow Tests	14
5.10.1 Airflow Calculations	15
5.10.2 Fabricate Model	15
5.10.3 Test Model	15
5.11 CRDEC Review of Preliminary Design	17
5.12 Detailed Design	18
5.12.1 Anthropometric Layouts	18
5.12.2 Lenses	18
5.12.3 Faceseal	21
5.12.4 Check Valves	29
5.12.5 Air Passage Ways	29
5.12.6 Void Spaces	29
5.12.7 Facepiece	33
5.12.8 Electronics	33
5.12.9 Filtration	42
5.12.10 Hood	44
5.12.11 Suspension	44

TABLE OF CONTENTS
(Continued)

	<u>Page</u>
5.12.12 Mask Assembly	44
5.13 Materials Selection	47
5.13.1 Input From Client	47
5.13.2 Criteria for Demonstrators	47
5.13.3 Selections Made	49
6.0 FABRICATION OF THE PROTOTYPE	50
6.1 Establish Procedure	50
6.2 Generate Basic Headform	50
6.3 Sculpt Facepiece Geometry	51
6.3.1 Faceseal	53
6.3.2 Lens	54
6.3.3 Void Space	57
6.3.4 Check Valves	57
6.3.5 Facepiece, Inside Surface	58
6.3.6 Facepiece, Outside Surface	58
6.3.7 Attachment Means	61
6.4 Cast Facepiece	61
6.4.1 Casting Materials	63
6.4.2 Vacuum Chamber	63
6.4.3 Elastomeric Resin Injector	64
6.5 First Casting	64
6.6 Epoxy Mold	65
6.7 Casting Facepieces With the Epoxy Mold	68

TABLE OF CONTENTS
(Continued)

	<u>Page</u>
9.2.1 Sculpt New Model	90
9.2.2 Generate Molds	94
9.2.3 Cast Facepieces	94
10.0 RESULTS	94
10.1 Final Description	94
10.2 Performance	97
11.0 CONCLUSIONS	97
12.0 RECOMMENDATIONS	98
APPENDIX A. DRAFT RESPO 21 DEVELOPER'S SPECIFICATION; M40 MASK REQUIREMENTS	A-1
APPENDIX B. BIBLIOGRAPHY; PATENT DISCLOSURE FOR MULTI-LAYER MASK	B-1
APPENDIX C. AIRFLOW SCHEMATIC PRESSURE DROP CALCULATIONS	C-1
APPENDIX D. QUOTATION FROM AMERICAN OPTICAL	D-1
APPENDIX E. LIST OF CANDIDATE MATERIALS FOR COMPONENTS OF MULTI-LAYER MASK	E-1

LIST OF FIGURES

	<u>Page</u>
FIGURE 1. ARTIST SKETCH OF MULTI-LAYER FACEPIECE ASSEMBLY	7
FIGURE 2. ARTIST SKETCH OF MULTI-LAYER MASK SUSPENSION	8
FIGURE 3. ARTIST SKETCH OF MULTI-LAYER MASK HOOD ASSEMBLY	9
FIGURE 4. CORRECTIVE LENS CURVATURES FOR -7.00 TO +1.12 DIOPTERS WITH COMMON BASE CURVE	11
FIGURE 5. AIRFLOW TEST RESULTS	16
FIGURE 6. CAD RENDERING OF ANTHROPOMETRIC REFERENCE HEADFORM	19
FIGURE 7. PRELIMINARY DETAIL DESIGN OF CORRECTIVE LENS, LEFT LENS SHOWN	22
FIGURE 8. EXPLODED VIEW OF LENS ASSEMBLY	23
FIGURE 9. PROTECTIVE LENS CONCEPTS WITH ELASTOMERIC BRIDGE ...	24
FIGURE 10. FACESEAL, SOLID ELASTOMERIC	26
FIGURE 11. GEL-FILLED FACESEAL	27
FIGURE 12. HIGH-PROTECTION FACESEAL	28
FIGURE 13. INHALATION CHECK VALVE	30
FIGURE 14. EXHALATION CHECK VALVE	31
FIGURE 15. AIR LINE CORES	32
FIGURE 16. FACEPIECE	34
FIGURE 17. MASK ASSEMBLY WITH PRELIMINARY LAYOUT OF ELECTRONICS	35
FIGURE 18. REMOVABLE BLOWER CONCEPT	36
FIGURE 19. CONCEPTS FOR BLOWER WITH HIGH-PROTECTION MODE OPTION	37
FIGURE 20. CENTRIFUGAL BLOWER, SHOWN POSITIONED ON HOOD BIB ...	39
FIGURE 21. VANE-AXIAL BLOWER, SHOWN POSITIONED ON HOOD BIB	40

LIST OF FIGURES
(Continued)

	<u>Page</u>
FIGURE 22. FILTER ELEMENTS, 48 SQ IN.	43
FIGURE 23. HOOD AND SUSPENSION ATTACHMENT CONCEPTS	45
FIGURE 24. MULTI-LAYER MASK ASSEMBLY	46
FIGURE 25. CAST HEADFORM	52
FIGURE 26. CORRECTIVE LENS INSERTS	55
FIGURE 27. MACHINABLE AIR PASSAGEWAYS	56
FIGURE 28. BUBBLE WRAP ON SCULPTURE	59
FIGURE 29. COVERING BUBBLE WRAP WITH LAYER OF PLASTER	59
FIGURE 30. COVERING BUBBLE WRAPPED SCULPTURE COMPLETELY WITH PLASTER	60
FIGURE 31. WRAPPING PLASTER LAYER WITH PLASTER BANDAGES	60
FIGURE 32. CORE MOLD WITH AIR LINE INSERTS AND PLASTER MOTHER MOLD	62
FIGURE 33. PLASTER MOTHER MOLD AND CASTING OF CAVITY SHOWING OUTER SURFACE OF MASK	62
FIGURE 34. HIGH STRENGTH SILICONE FACEPIECE	66
FIGURE 35. EPOXY CORE	67
FIGURE 36. EPOXY CORE WITH DENTAL STONE AIR LINE INSERTS	67
FIGURE 37. EPOXY CORE WITH DENTAL STONE AIR LINE INSERTS AND EPOXY SIDE PIECES OF CAVITY	69
FIGURE 38. ASSEMBLED EPOXY MOLD WITH RESERVOIRS	69
FIGURE 39. INJECTING ALIPHATIC URETHANE INTO EPOXY MOLD ASSEMBLY	70
FIGURE 40. ALIPHATIC URETHANE FACEPIECE WITH AIR LINE INSERTS IN PLACE	73
FIGURE 41. ALIPHATIC URETHANE FACEPIECE	74

and a new prototype was fabricated. Finally, this second prototype was evaluated. This report describes these tasks and provides conclusions and recommendations for this program.

2.0 DESIGN GOALS

The three design goals for the RESPO 21 multi-layer mask were to maintain protection against the future threat, reduce mission degradation, and improve integration with current and future equipment.

In order to maintain protection against a future threat, several improvements must be made to the M40 mask. Materials with enhanced agent protection capabilities when compared to the M40 mask materials will have to be used. Reduced breathing resistance will also be required which can be obtained by adding a blower to the filtered air supply. Finally, by improving the fit or conformity of the mask over a range of sizes and facial profiles, the protection against future threats can be maintained.

To reduce mission degradation caused by current designs, the multi-layer mask needs to improve comfort, visibility, and communication. In addition, a reduction in mission degradation can be achieved by reducing the thermal burden on the mask wearer and increasing the ease of recognition between mask wearers.

Improving integration with current and future equipment requires minimizing the lens stand-off to permit use of night vision sighting devices, reducing the exterior profile of the mask to enhance rifle sighting and firing, and miniaturizing and lightening components to reduce the bulk and the profile of the hood assembly to minimize interference with armor vests, backpacks, and other equipment worn by the soldier.

These goals were set for the RESPO 21 multi-layer mask and were used as the basis for the designs developed during this program.

3.0 REVIEW OF PREVIOUS WORK

The preliminary performance requirements for the multi-layer mask were provided at the beginning of the program. Other requirements were introduced at various stages of development. The requirements provided at the beginning of the program were a set of Draft RESPO 21 Developer's Specifications and the M40 Mask Requirements (Joint Service Operation Requirements). These are included in Appendix A.

5.1 Preliminary Design

With the stated requirements, functional characteristics, and design goals, a preliminary design was prepared using the components of the multi-layer mask. Figures 1, 2, and 3 show artists sketches of the different components of the multi-layer mask preliminary design. The objective of the preliminary design was to communicate the general layout and assumptions for the multi-layer mask to the client. The preliminary design of the multi-layer mask includes the following components:

- Facepiece
- Optical inserts
- Laser protection
- Peripheral faceseal
- Hood
- Barrier film
- Filter
- Electrical components
- Blower
- Controls

5.2 Facepiece

Originally, as stated in the multi-layer mask patent disclosure, the facepiece was envisioned to be made of three distinct layers which were to be mechanically attached. The outside layer would provide protection from liquid agent, the intermediate layer would provide structural support, while the inner layer would encapsulate the faceseal and thus, would be made of a material that would be compatible with skin contact. All the layers were to be transparent to allow recognition of the user. Also, the 3-layer assembly would need to be flexible to accommodate weapons sighting.

This approach implied that the facepiece would become an assembly of three distinct layers, of different materials that would need to be held together by some unspecified means. In addition to the layers, an airflow system needed to be incorporated into the design to allow filtered air to be drawn into the mask, across the lenses, and into the users lungs. The candidate approach for fabricating the 3-layers appeared to be vacuum thermoforming. After thermoforming the layers, it would be necessary to intimately attach the layers together to evaluate the airflow through the mask. After assessing the given design characteristics it was

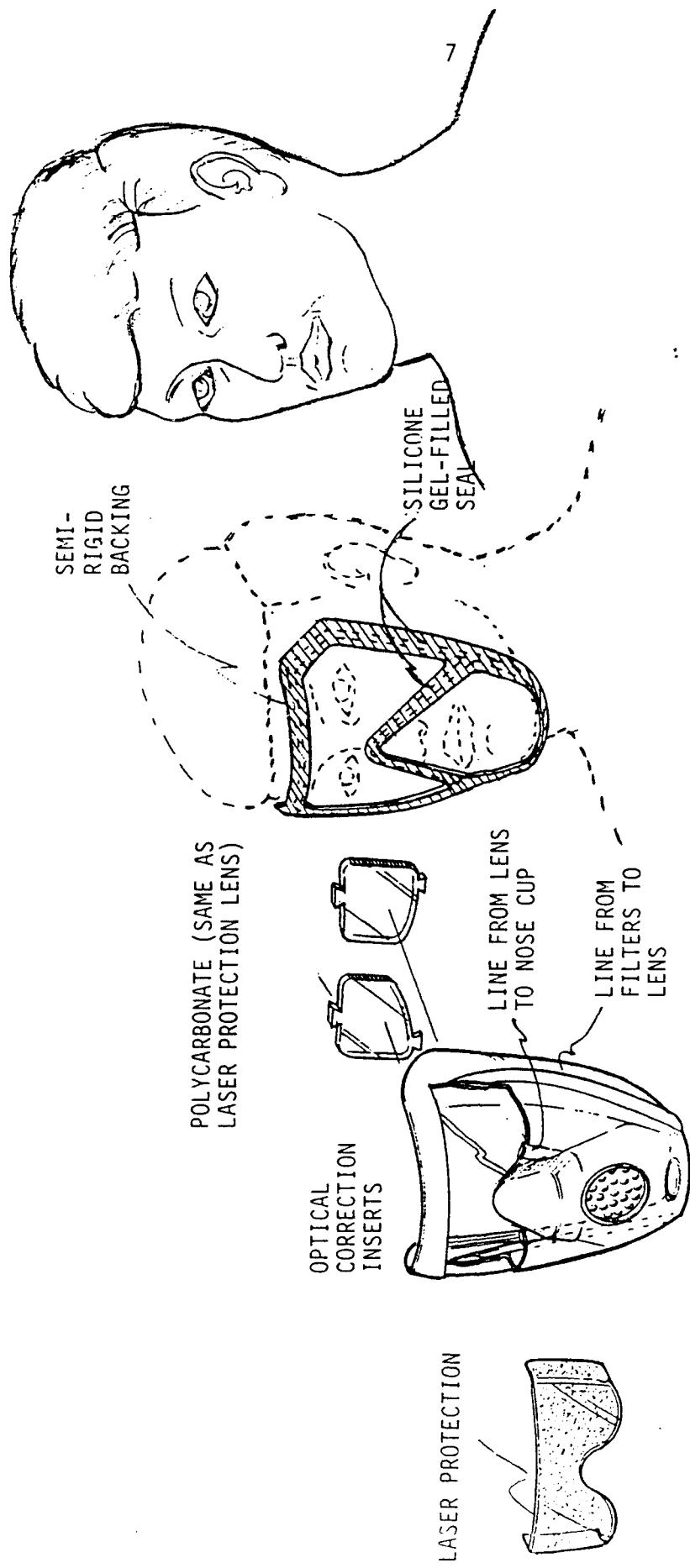


FIGURE 1. ARTIST SKETCH OF MULTI-LAYER FACEPIECE ASSEMBLY

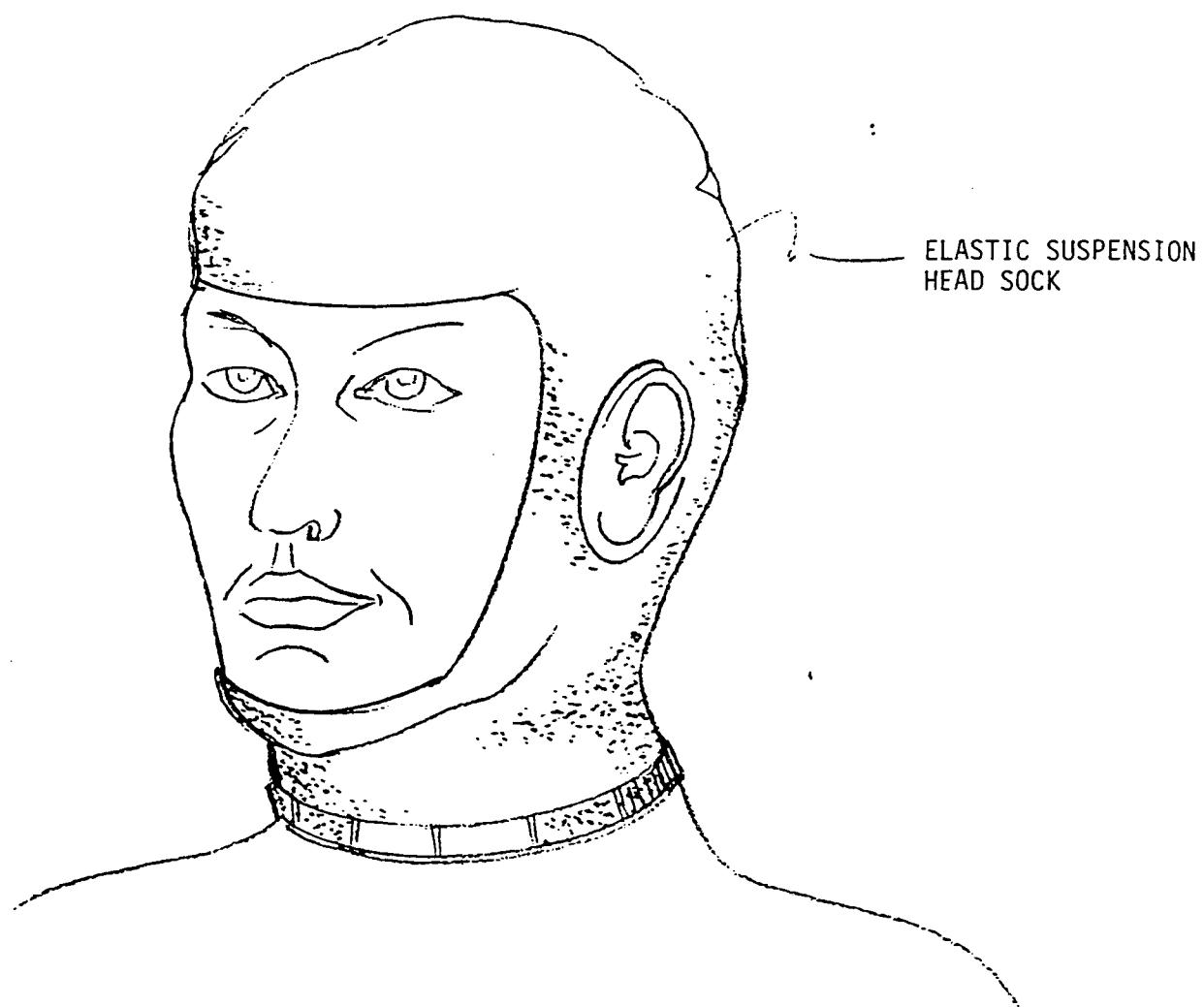


FIGURE 2. ARTIST SKETCH OF MULTI-LAYER MASK SUSPENSION

LIQUID AGENT RESISTANT
HOOD WITH BIB SUPPORTING
FILTER/BLOWER UNIT

9

OPTIONAL : BARRIER FILM TO COVER
STRUCTURAL (URETHANE)
LAYER IF NEEDED

LASER PROTECTION

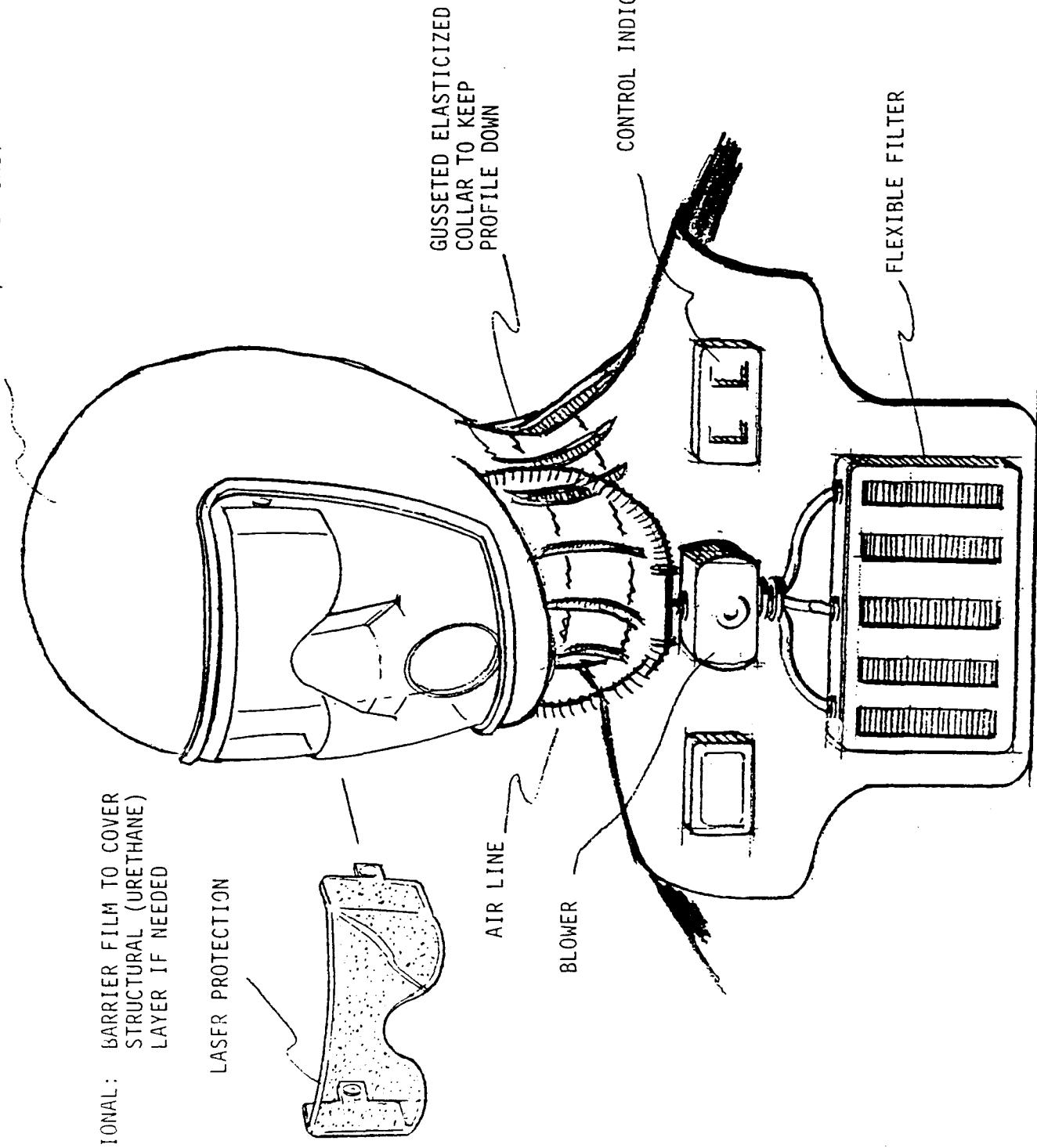


FIGURE 3. ARTIST SKETCH OF MULTI-LAYER MASK HOOD ASSEMBLY

determined that fabricating the facepiece from three distinct layers within the time and cost limitations of the funded program would not be practical. A simpler approach was needed.

The simpler approach identified was to incorporate the airlines into the intermediate layer. This would be accomplished by casting the intermediate layer out of an optically clear elastomeric material and utilizing removable cores to form the airlines. Then, instead of dedicating an entire layer to the inner layer, or seal surface, a separate faceseal would be fabricated that could be attached to the intermediate layer. This approach would allow the faceseal to be replaceable for design optimization and replacement. The outer layer could still be a thin film of material which would be resistant to liquid chemical agent.

5.3 Optical Inserts

One of the desirable features of the multi-layer mask was to configure the lens system into three distinct layers, similar to the envisioned 3-layer design for the facepiece. The intermediate lens would be an integral part of the intermediate facepiece. Since the intermediate lens would be part of the intermediate facepiece, the material selected for the intermediate facepiece would have to be made out of an optically clear material.

The optically corrective lenses should be insertable into the inside of the facepiece. These lenses would need to accommodate the range of prescriptions from the 1 to 99th percentile soldier that would potentially be using the multi-layer mask. Originally it was assumed that the optical prescriptions could range from -9 to + 9 diopters. This range of nearsighted to farsighted prescriptions resulted in quite a wide spread of potential lens curvatures. This range would require separate masks designs in order to maintain the desired field-of-view coupled to the desired maximum lens stand-off. Later in the program supplemental data was supplied from "Visual Survey of Infantry Troops, Part 1: Visual Acuity, Refractive Status, Interpupillary Distance, and Visual Skills" by David J. Walsh, Sensory Research Division June 1989, which grouped the range of optical prescriptions statistically. The results of this data indicated that the majority of the expected corrective lens prescriptions for the group targeted for wearing the multi-layer mask fell into the range of -7.00 to + 1.12 diopters. This range was much easier to accommodate from a design perspective. Provided with this information, a common face curvature was selected for all of the potential lens curvatures which is shown in Figure 4.

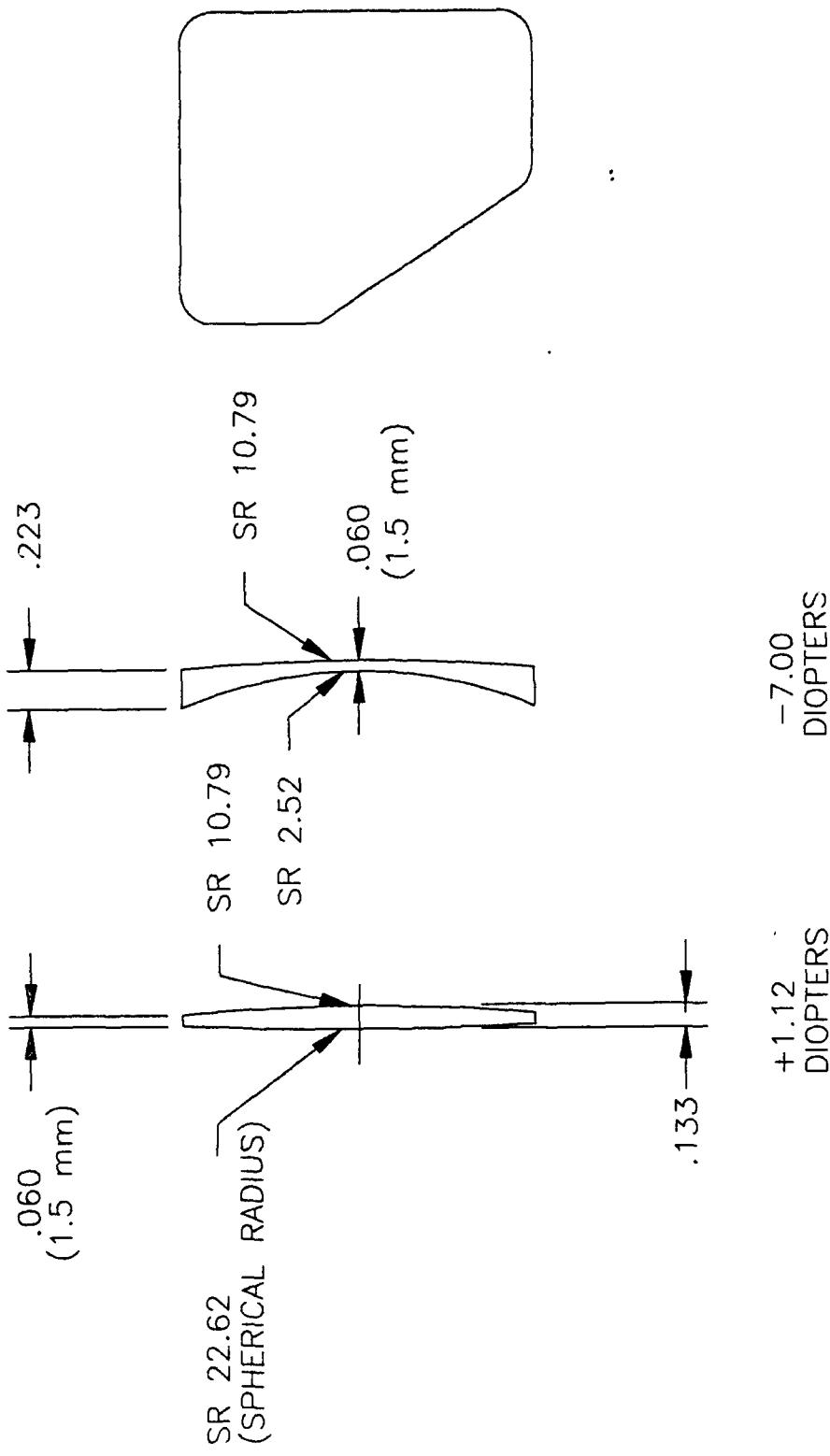


FIGURE 4. CORRECTIVE LENS CURVATURES FOR -7.00 TO
+1.12 DIOPTERS WITH COMMON BASE CURVE

5.4 Laser Protection

In addition to the intermediate lens and the corrective lens, it was desirable to have the option to attach a protective lens to the outside of the facepiece. The purpose of the protective lens would be to provide protection against impact of particles and debris protecting both the wearer and the softer, more vulnerable intermediate lenses. In addition to the impact protection, it was desirable to protect the mask wearer from harmful lasers commonly used in the modern battlefield environment. In some instances, the protective outer lens was required without the darkening tint indicative of laser protective lenses. Therefore, it was planned to make both tinted and non-tinted protective lenses available for the demonstrator model of the multi-layer mask.

5.5 Peripheral Face Seal

The peripheral face seal was envisioned to be made from a stretchy rubber-like material that could be pre-formed into a trough-like geometry that would follow the contours of the human face. The trough-like shape could then be filled with a conforming gel and backed possibly with a foam cushion or an air bladder to support the gel and distribute the load of the face seal evenly over the contact line on the face. It was also desirable to make the peripheral face seal removable from the facepiece to facilitate anticipated design modifications to the cross-sectional geometry of the face seal during optimization. The face seal was designed with a flange on the back side to snap into place into a groove which could be molded into the facepiece.

5.6 Hood

A hood was needed that would attach to the peripheral edge of the facepiece. The hood would cover the top, sides and back of the head as well as incorporate a bib for support of the filtration system and the electrical components. The material selected for the hood needed to be chemical agent resistant as well as exhibit material properties that would be conducive to a drapeable conforming fit. It was desirable to select a material that was not too stiff so that it would inhibit head movement by the mask wearer. At the same time the material should not be noisy, which is influenced by material stiffness, composition and surface finish.

If the material selected for the hood is chemical agent resistant and fully decontaminable, it should be permanently attached to the facepiece. If the hood is made of a breathable material, and thus used a chemical agent adsorbing carbon material, it should be removable from the facepiece, after prolonged exposure to chemical agents. This implies that the attachment means of the hood to the facepiece would have to permit removal of the hood for disposal. During the program, the optimum hood material was never clearly established so for demonstrator purposes the hood was simply sewn onto the facepiece.

5.7 Barrier Film

Since the facepiece may be fabricated from a material that does not provide full protection from chemical agents, a material is needed to cover the facepiece and act as a barrier to chemical agent. Early in the program it was assumed that the barrier film would cover the facepiece except around the lens area. The assumption was that the protective lens would make contact with the barrier film around the lens area of the facepiece. Potential materials for the barrier film were relatively thin, stiff and translucent. It was assumed that in order to insure an intimate fit, the barrier film could be vacuum thermoformed over a pattern representing the outside geometry of the facepiece. Because of this approach, the barrier film could not be made until the facepiece geometry was well established.

Other options investigated for a barrier film include coatings and vapor depositions. Both of these approaches showed promise depending on the substrate to which they were applied and the environmental conditions to which they were subjected. Although not tested during this program, coatings and vapor depositions could potentially provide a convenient method to enhance the chemical agent resistance of a given facepiece material.

5.8 Filter

The filtration system will consist of both agent and particle filter materials. For simplicity, the multi-layer mask filtration materials were assumed to function as an in-one-side-out-the-other filtration approach. One surface of the filter material would be exposed to the ambient, potentially contaminated, air. The other side of the filter material would be supported by spacer material that would allow the clean filtered air to flow into a plenum. From the

plenum, the filtered air would flow through a section of tubing that would connect to the air lines on the facepiece.

5.9 Electrical Components

The electrical components required for the multi-layer mask include a blower for directing filtered air into the facepiece, a communications system including a microphone, amplifier and speaker system, and a power supply.

5.9.1 Blower

The blower was intended as an optional feature for the multi-layer mask. Earlier studies conducted by CRDEC indicated that a blower supplying 2 CFM into a mask would provide increased protection as well as psychological and cooling advantages. This study was apparently based on tests run with the M43 mask. As a result of the study, it was determined that adding an auxiliary 2 CFM blower to the M43 mask system would provide significant advantages with regard to protection factor, cooling, and even psychologically.

During the preliminary design for the multi-layer mask, it was determined that a 2 CFM blower could be added to boost the airflow.

5.9.2 Other Electrical Components

The other electrical components, the communications and power supply systems, are under development by Battelle's Electronics Department. The design of these components will be discussed in that report.

5.10 Critical Airflow Tests

After the preliminary design of the multi-layer mask was established identifying the individual components and primary function of the components, critical tests were conducted to establish the air passages through the mask system. Initially, the air passages were laid out to accommodate the assumed airflow path through the facepiece and the natural contours of the human face. The candidate airflow path enters the facepiece at the lower portion of the mask along the jawline, follows up the side of the face to the temples, and fans out entering the space between the eye and the mask lens. The airflow continues from the space in front of the eye

through a duct that crosses over the face seal bridging the nose and into the mouthcup area. This arrangement allows clean, dry air to be inhaled into the airlines along the side of the face, across the lenses to minimize fogging, and over the face seal and into the mouth/nose cup area.

5.10.1 Airflow Calculations

Assumptions were made to define the geometry of the air lines that would best suit prototyping. The cross-sectional area was based initially on a scuba snorkel. A preliminary drawing of the geometry of the air lines is included in Appendix C. Using basic fluid dynamics equations, calculations were made of the expected pressure drop that would occur through the proposed airlines subjected to a design airflow of 85 liters per minute (lpm). A summary of the pressure drop calculations is also included in Appendix C. According to the RESPO 21 Developer's Specification, it was desirable to maintain the inhalation breathing resistance of the multi-layer mask system to less than 30 mm water at a flow rate of 85 lpm. By comparison the M40 Operational Requirements state an inhalation breathing resistance of no greater than 55 mm water at 85 lpm.

5.10.2 Fabricate Model

In order to verify the airflow calculations with the proposed airline geometry, a model was built and the flow conditions were tested. A headform was obtained and air lines were constructed that were of approximately the same geometry as that used for the calculations.

5.10.3 Test Model

Using a controlled air supply a range of airflows were blown through the model and subsequent pressure readings were recorded. The results are compiled graphically in Figure 5. The test results with the model were in close agreement with the airflow calculations thus validating our preliminary design.

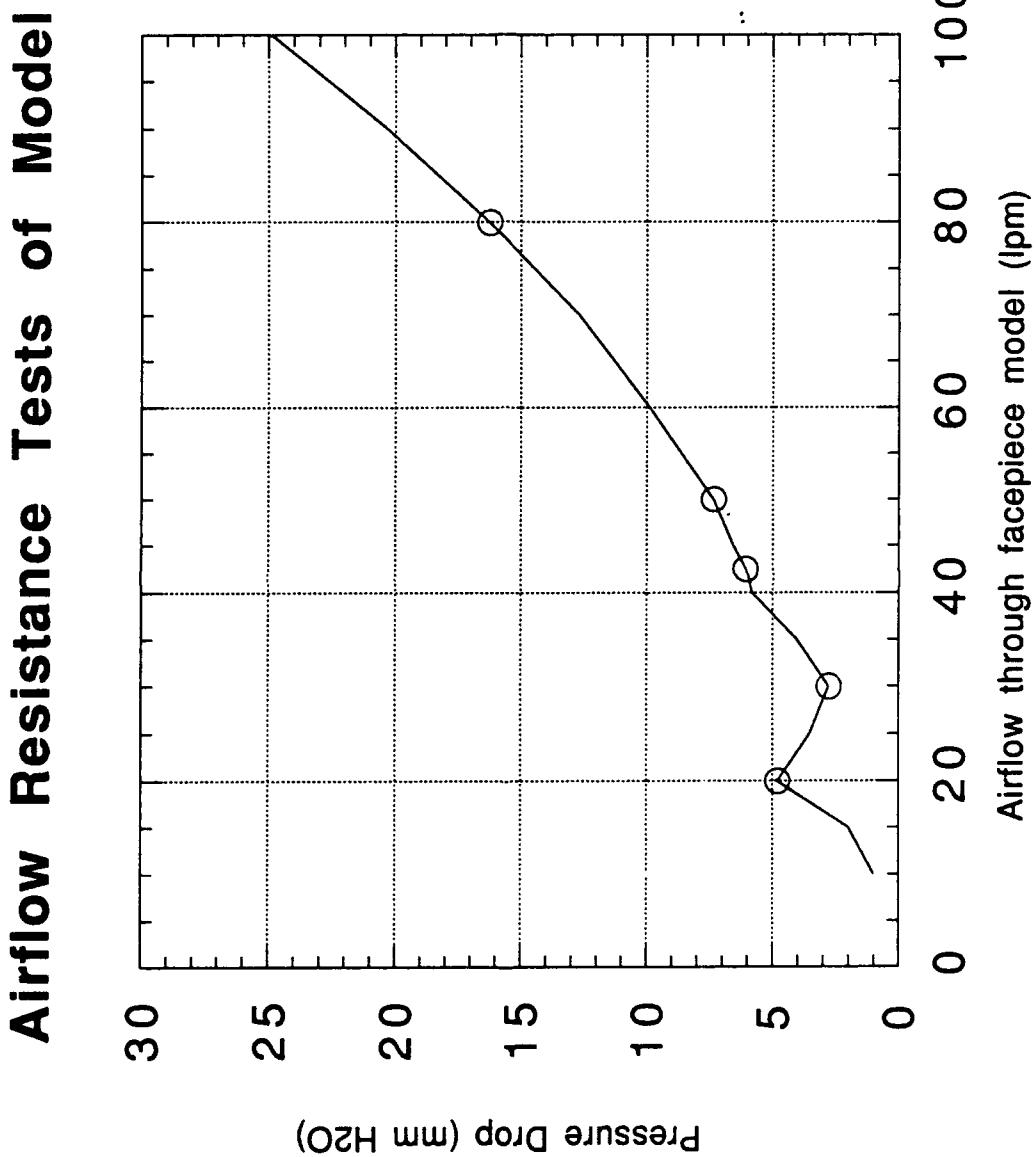


FIGURE 5. AIRFLOW TEST RESULTS

5.11 CRDEC Review of Preliminary Design

The sketches of the preliminary design (Figures 1, 2, and 3) were submitted to the client for review and comments. After studying the sketches, the following comments were returned to Battelle:

Laser protection - One piece lens design will break in the middle if folded. May correct by thinning in the middle or providing a urethane bridge.

Facepiece - May want to eliminate voicemitter and bond in thin clear film initially. Rifle firing will require checks as close as possible.

Faceseal - Did not address high protection mode, that is, an air pocket around the outside of the faceseal that continuously blows air outward away from face. Also, envisioned pump up air bladder backing in faceseal.

Suspension - How does the suspension attach to mask (facepiece)? May be difficult to don full head suspension.

Hood - Envisioned more streamlined bib area. Hose should contour with neck to avoid snagging. Need to add cord for communication hookup, drinking tube, pump for drinking along with bladder containing fluid for drinking, and power source location and amplifier. Bib should be attached with snaps along top for easy change and a quick release for hose under bib. Envision 3 modules, power, blower, and amplifier.

With the feedback from CRDEC, Battelle proceeded to modify the design addressing the areas of concern. After modifying the preliminary design, the major components were adequately defined so that the design could proceed to the next level.

5.12 Detailed Design

In order to establish an accurate representation of the proposed multi-layer mask design, a detailed design was generated using a CAD system. This approach resulted in scale representations that help clarify design details to facilitate the model making procedure.

5.12.1 Anthropometric Layouts

Work began on the detailed layout by establishing a reference for all of the mask components. Since this is a design that will fit on or around human features, data describing and dimensioning these features over the cross-section of population for which the multi-layer mask is intended is needed. This information is referred to as anthropometric data. Several sources of anthropometric data were studied for use in generating a basis for the multi-layer mask design. After reviewing the sources, the 1988 Anthropometric Survey of U.S. Army Personnel: Summary Statistics Interim Report compiled by John T. McConville, et al., of the Anthropology Research Project, Inc. Yellow Springs, Ohio, was selected as most appropriate. This survey was compiled from a subset of personnel (1774 men and 2208 women) sampled to match the proportions of age categories and racial/ethnic groups found in the active duty Army of June, 1988.

The anthropometric data included 132 standard measurements statistically distributed from the 1 to 99th percentile. The data included sixty derived dimensions calculated largely by adding and subtracting standard measurement data, and 48 head and face dimensions reported in linear terms but collected by means of an automated headboard designed to obtain three-dimensional data.

In this program, sizing the multi-layer mask to cover all head sizes was not a requirement so the mask was designed for an average size male head using the 50th percentile data for a man. A two-dimensional layout was generated with this data of a generic headform (as shown in Figure 6) using the CAD system. From this two-dimensional layout we proceeded to design the individual mask components.

5.12.2 Lenses

The desire to minimize the stand-off distance of the lens from the eye was important in order to accommodate sighting systems such as the Aviator Night Vision Imaging System

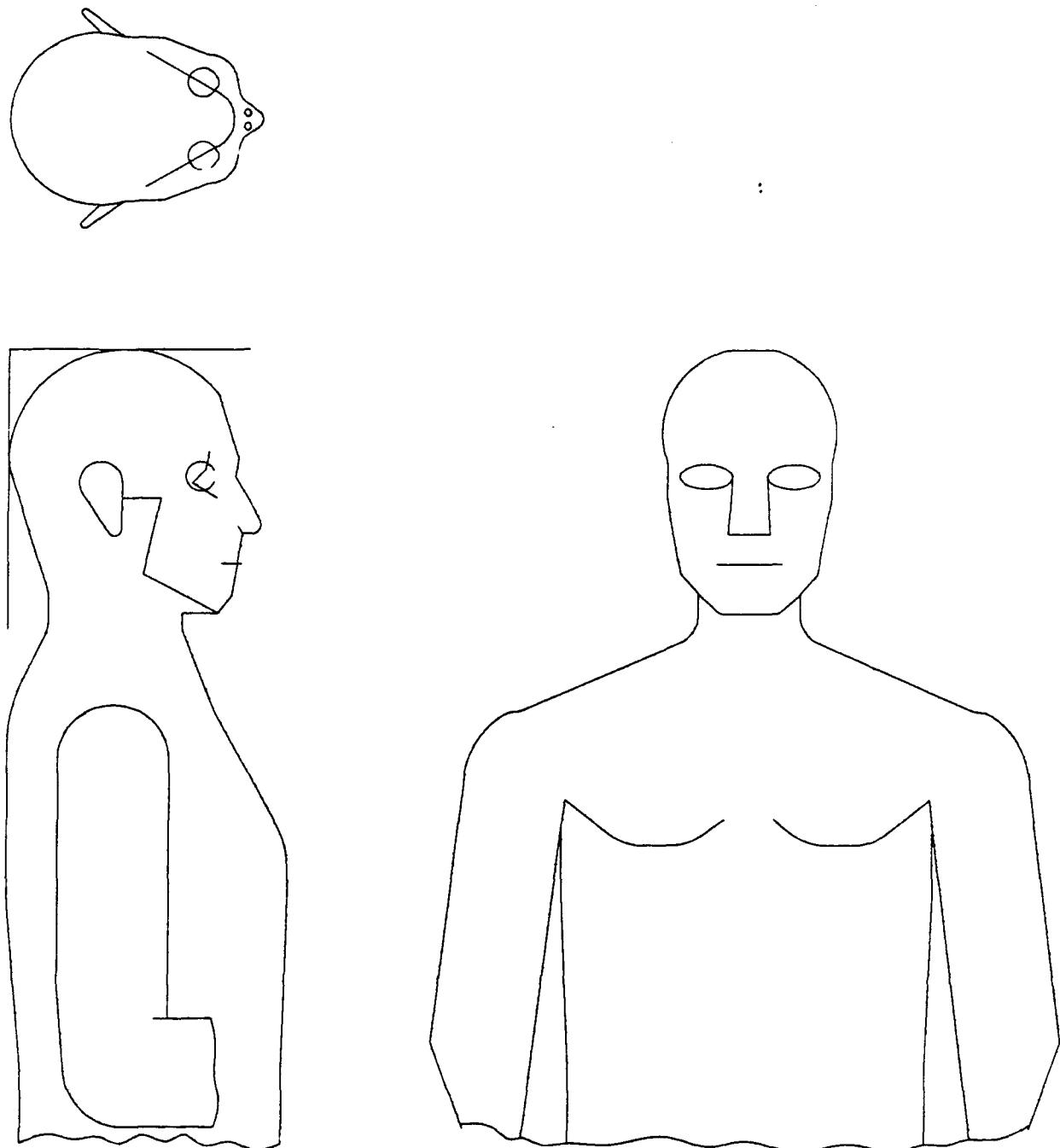


FIGURE 6. CAD RENDERING OF ANTHROPOMETRIC
REFERENCE HEADFORM

(ANVIS). According to the multi-layer mask patent disclosure, this stand-off distance should be kept below 25 mm (under 1 inch). In order to achieve this minimum stand-off distance, it became necessary to determine the minimum distance that a corrective lens could be placed from the cornea of the eye, and couple that with the range of expected curvatures and thicknesses of the corrective lenses.

5.12.2.1 Optics

In order to design the corrective lenses for the multi-layer mask, it was necessary to establish some basic assumptions. The recommended distance from the front of the eye (the anterior vertex of the cornea) to the inside surface (back curve) of the corrective lens should be about 12 to 15 mm according to the Optical Society of America, "Handbook of Optics". This distance is stated as a range, presumably due to the fact that eye shape, facial features and eyelash length can vary from person-to-person. For design purposes, it was assumed 12 mm would be the absolute minimum distance from the eye to the corrective lens.

After establishing the minimum distance from eye to lens, the next step was to determine the thickness of the lenses (at the line of sight) as well as establish the base and back curvatures of the lenses over the range of probable prescriptions. If we assumed that the lens would be made out of a plastic material such as polycarbonate then an acceptable minimum thickness for a corrective lens was 1.5 mm. Minimum thickness for safety lenses is 3 mm, but since the multi-layer mask will use an impact protective lens fit onto the exterior of the mask then it would be redundant and add unnecessary thickness to the lens system to require the corrective lens to meet safety (impact protection) standards.

It was desirable, if possible, to maintain a single base curve (opposite of the back curve or the front of the lens) for the corrective lenses so that the multi-layer mask facepiece could be designed to accept a range of prescriptions. Early in the program, the range of probable optical prescriptions that would be encountered was determined among the personnel for which the multi-layer mask is intended was identified. A range of + 9.0 to -9.0 diopters was recommended. This represented quite a spread of lens curvatures. After looking at some of the probable lens curvatures to accommodate the wide range of prescriptions, it was determined that it would require no fewer than three base curves to allow for a stand-off of less than 25 mm (1 inch) and to maintain a minimum lens thickness of 1.5 mm. Later in the program, a more representative

range of +1.12 to -7.00 diopter was identified which could be accommodated with a single base curve.

Another factor to consider for the optical corrective lens is to establish whether the lens should be designed to contact the surface of the facepiece intermediate lens. For the first iteration the optical corrective lens was designed to contact the facepiece lens since this arrangement would minimize reflections between the two lenses and possibly reduce the occurrence of fogging between the lenses. An arrangement of the initial lens design is shown in Figure 7. For the initial model, a nominal base curve was selected to cover the range of +1.12 to -7.00 diopter optical prescriptions.

5.12.2 Protective

With the optical corrective lens geometry established, and assuming a 1.5mm (0.060 inch) thickness for the facepiece lens, a protective lens geometry was configured to complete the lens system. The lens system assembly is shown in exploded view in Figure 8. Options were explored to incorporate an elastomeric material between the two protective lens halves. One of these options shown in Figure 9.

After a layout of the lens system assembly was defined and prepared, it was decided to submit the design to an optical company for analysis, evaluation and consultation. The lens assembly design was sent to Clark Grendol of American Optical Corporation and a quotation requested. This quotation was received from American Optical and is included in Appendix D of this report. After discussing the quotation with CRDEC, the lens system analysis was postponed until the molding procedure for the optically clear facepiece could be established.

5.12.3 Faceseal

The faceseal was designed and developed to surround the periphery of the face and cross over the nose isolating the eye void space from the mouth/nose cup void space. The faceseal was positioned to minimize interference with the lens system, mouth/nose cup check valves, and air lines yet not drastically increase the perimeter of the facepiece. The cross sectional area was modeled after a gel-filled faceseal that was fabricated for a previous program conducted by Battelle for CRDEC dealing with novel seals and attachment methods for RESPO 21. The cross section of the faceseal was kept to a minimum to help maintain a closer fitting profile for the

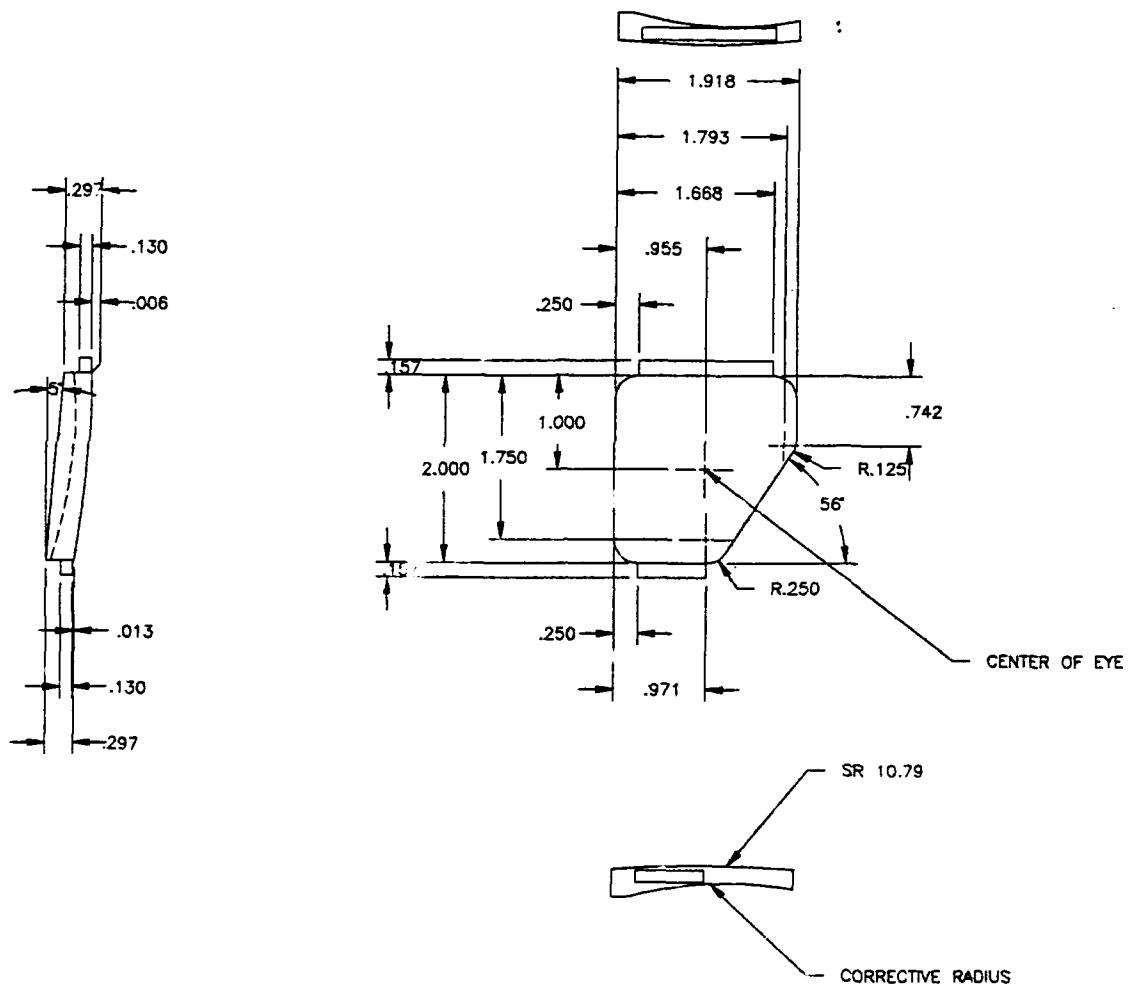


FIGURE 7. PRELIMINARY DETAIL DESIGN OF CORRECTIVE LENS, RIGHT LENS SHOWN

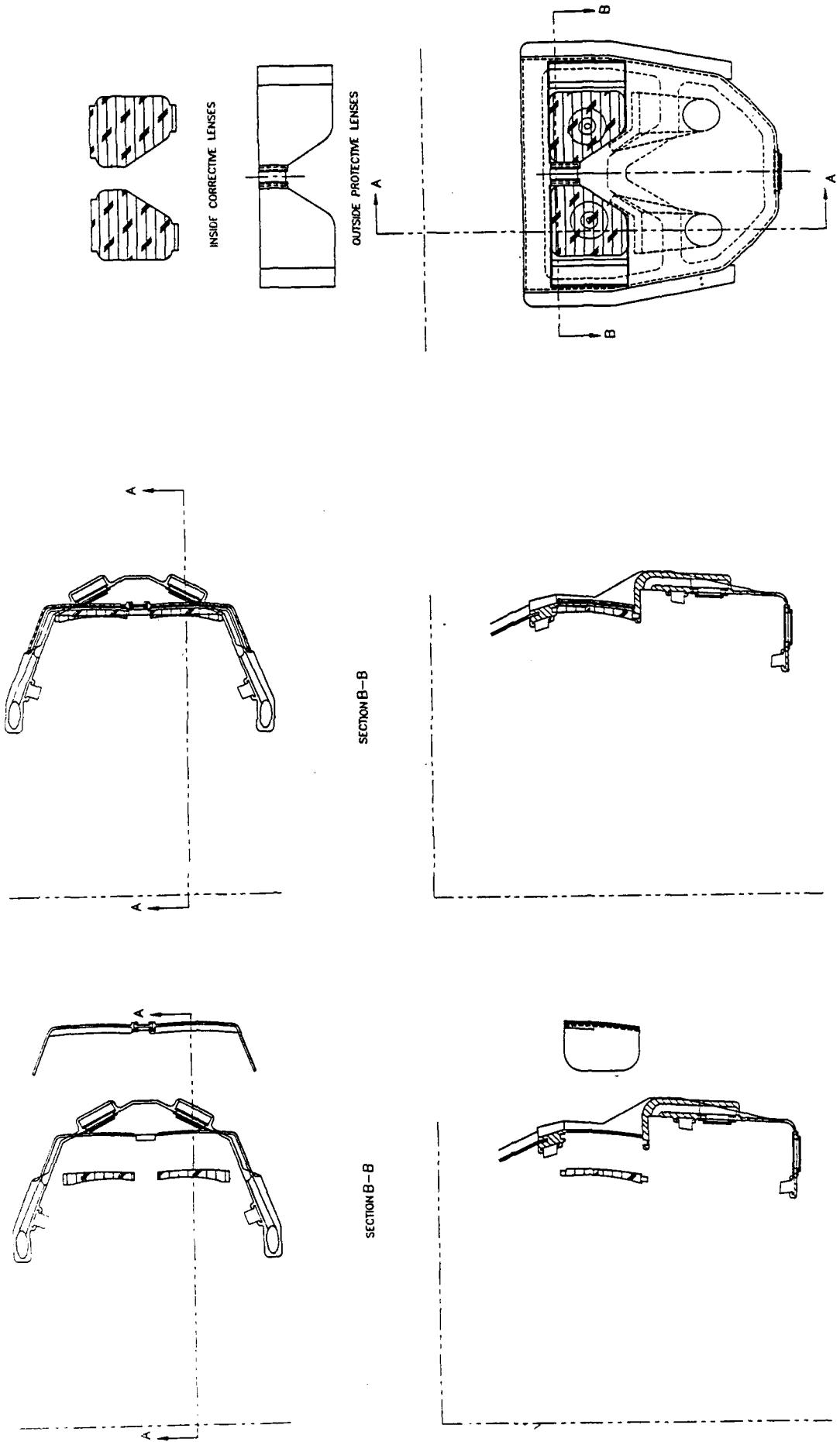


FIGURE 8. EXPLODED VIEW OF LENS ASSEMBLY

multi-layer mask facepiece. A drawing of the envisioned seal is shown in Figure 10. The faceseal was configured with a flange on the back side. This flange provides a simple means with which to attach the faceseal to the facepiece.

5.12.3.1 Solid Elastomeric

For the initial model of the multi-layer mask, a solid faceseal would be cast out of an elastomeric material. This would enable the fit of the faceseal flange into the mating slot on the inside surface of the facepiece to be checked. Fabricating a mold for the solid elastomeric faceseal would enable a variety of castable elastomeric materials to be tried and thus an appropriate hardness to be selected for modeling purposes.

5.12.3.2 Gel-Filled

Based on the work conducted on a previous Battelle project for CRDEC titled "Novel Seals and Attachment Mechanisms for RESPO 21" it was determined that a gel-filled faceseal would exhibit the right properties of compliance and comfort. As the solid faceseal was being designed, developed and fabricated, work was conducted to determine the best way to obtain a gel-filled faceseal. Figure 11 shows the cross-sectional configuration of an early approach for the gel-filled faceseal. Candidate materials for the faceseal include a silicone-base dielectric gel encapsulated in a thin Kraton (synthetic rubber) skin.

5.12.3.3 High Protection

Early review of the preliminary design of the components comprising the multi-layer mask resulted in the preparation of an optional faceseal design. This design would include an additional tube that would be coupled to the outside edge of the periphery of the faceseal. This outside tube would be continuously pressurized with a moderately low flow of filtered air. Small perforations in the inside edge of this tube would allow the filtered air to leak out slowly surrounding the face with, essentially, an air curtain. This approach would provide additional protection independent of the primary faceseal. A sketch of the high protection seal is shown in Figure 12.

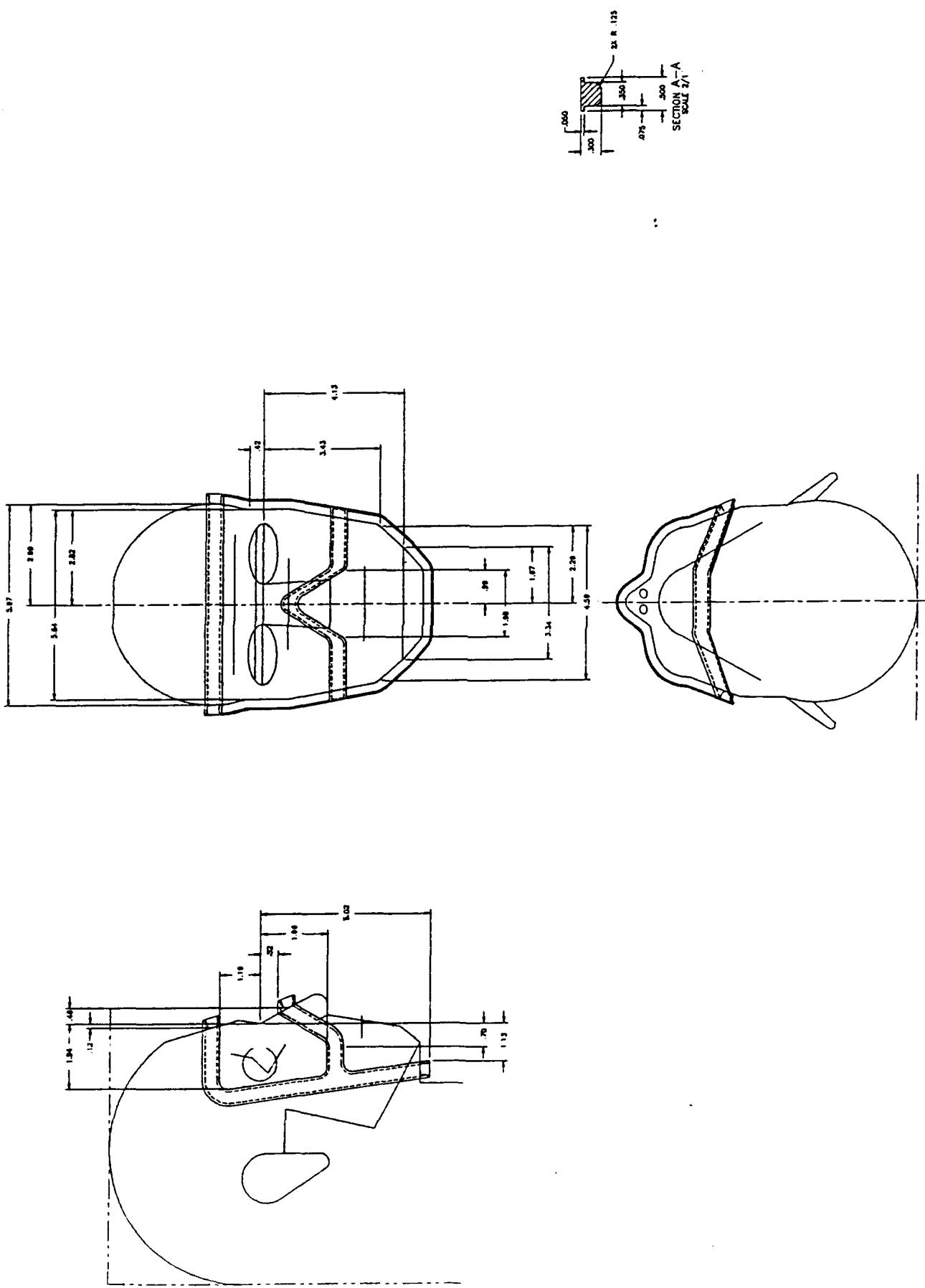


FIGURE 10. FACESEAL, SOLID ELASTOMERIC

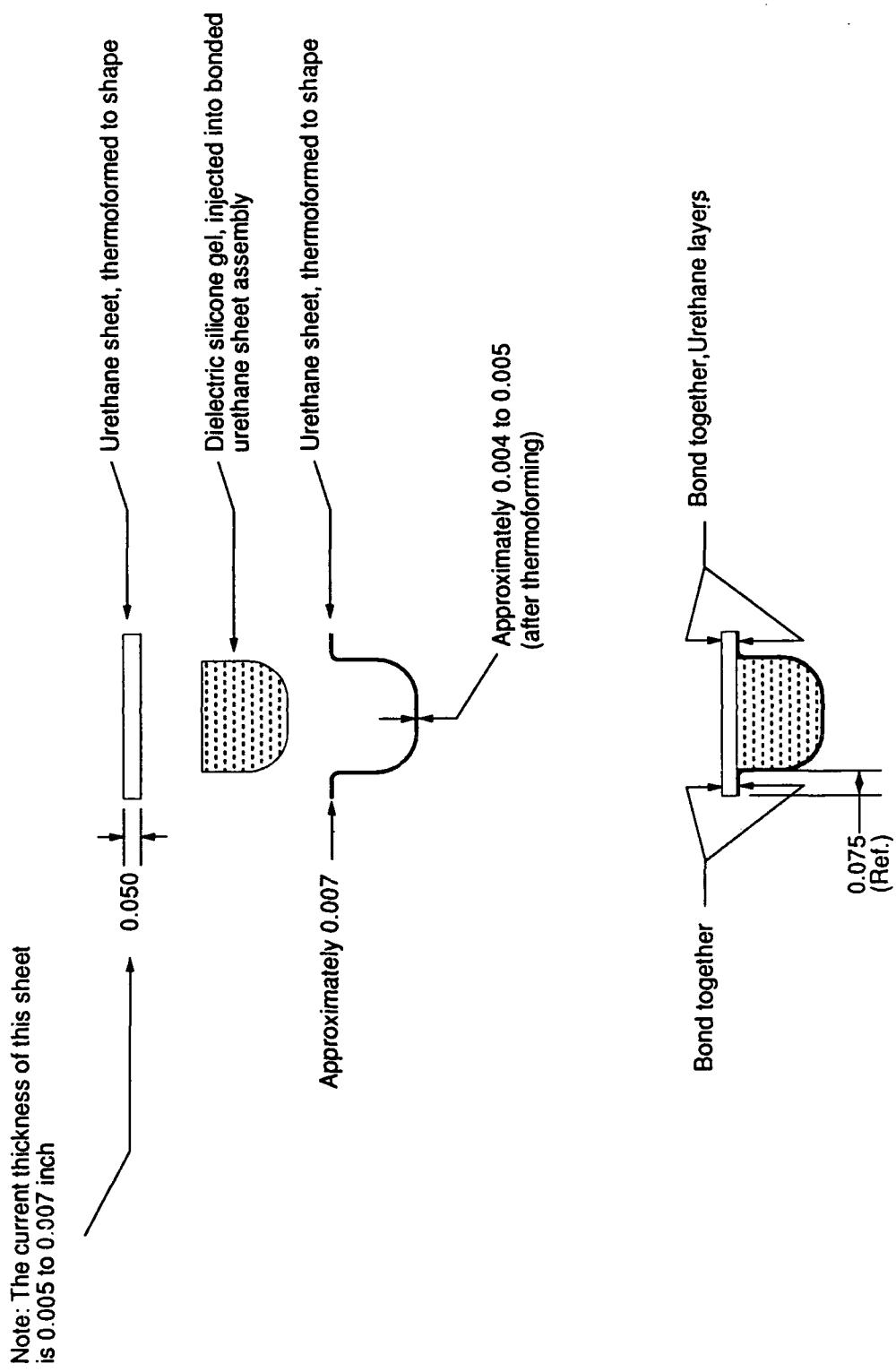


FIGURE 11. GEL-FILLED FACESEAL

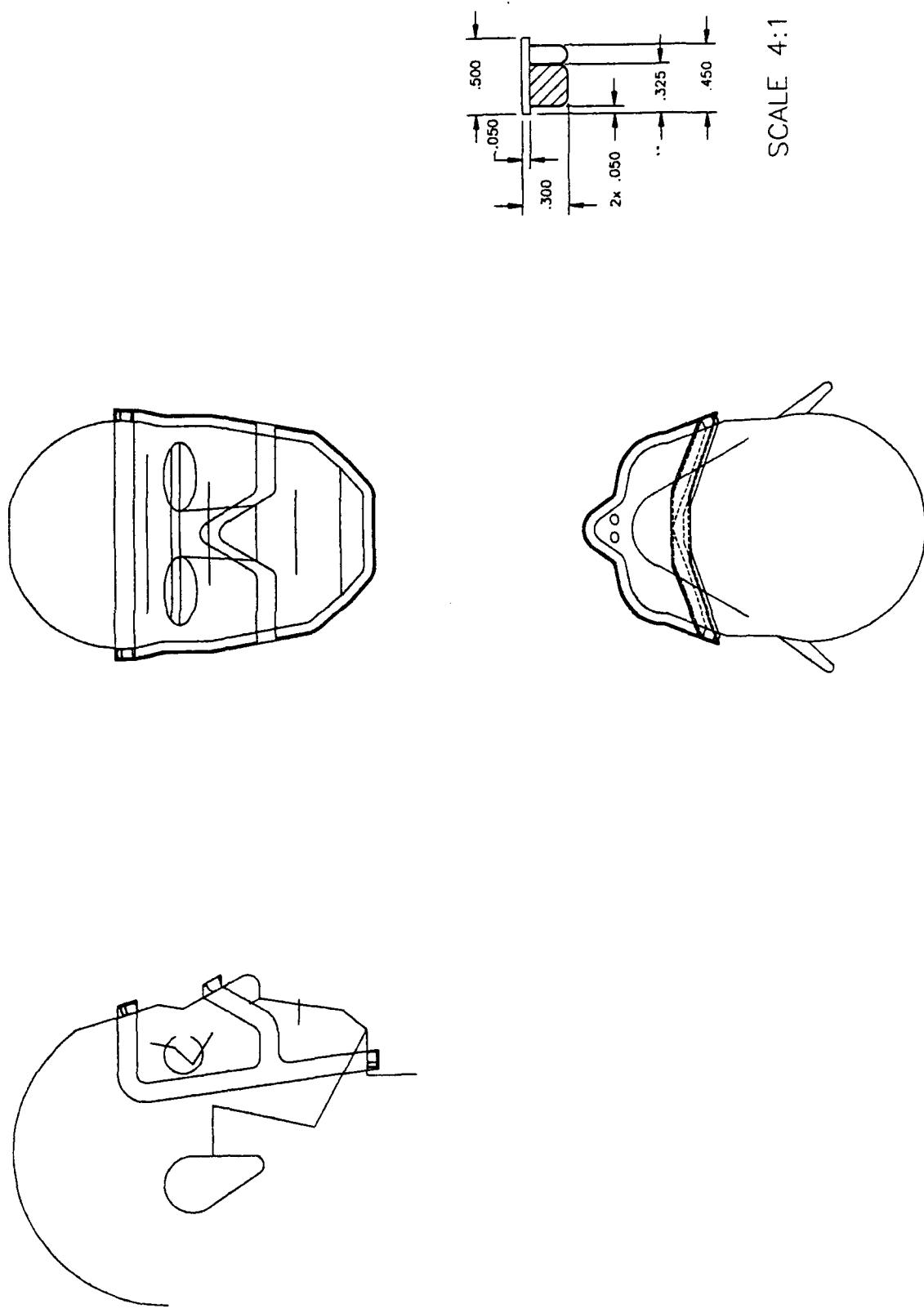


FIGURE 12. HIGH-PROTECTION FACESEAL

5.12.4 Check Valves

A total of three check valves are required for the multi-layer mask. Two check valves are located at the two air lines that enter the mouth/nose cup area. These check valves prevent moist exhaled air from flowing into the lens area fogging the lens. The third check valve is located at the bottom of the mask near the chin. This check valve permits the exhaled air from the lungs to leave the mask flowing outside into a potentially contaminated environment.

Initially, check valves were designed and fabricated to match-up with the cross-sectional area of the facepiece airlines. It was desirable to keep the check valves as small as possible to minimize the outside profile of the facepiece. Sample check valves were designed and fabricated for the initial model. These valves are shown in Figures 13 and 14.

5.12.5 Air Passage Ways

The air passage ways were designed to maintain an even flow of air throughout the mask. The initial air passage ways or air lines were configured of a regular geometry to allow machining of the cores for use when molding the facepiece. The intent was that machining the air line cores would be one way to maintain consistency for one of the more functional aspects of the demonstrator mask. The air lines were designed in pieces to both facilitate machining of the cores and allow for removal of the cores during the casting process. Figure 15 shows the air line cores as designed.

5.12.6 Void Spaces

After the lenses, faceseal, and air lines were established, it became necessary to define the void space desired at each area inside the facepiece. Most notably are the areas in and around the eyes, the nose/mouth cup area, and the amount of space required outside of the faceseal. These spaces were somewhat difficult to describe on the CAD drawings so most of the void spaces were configured during the sculpting of the mold forms.

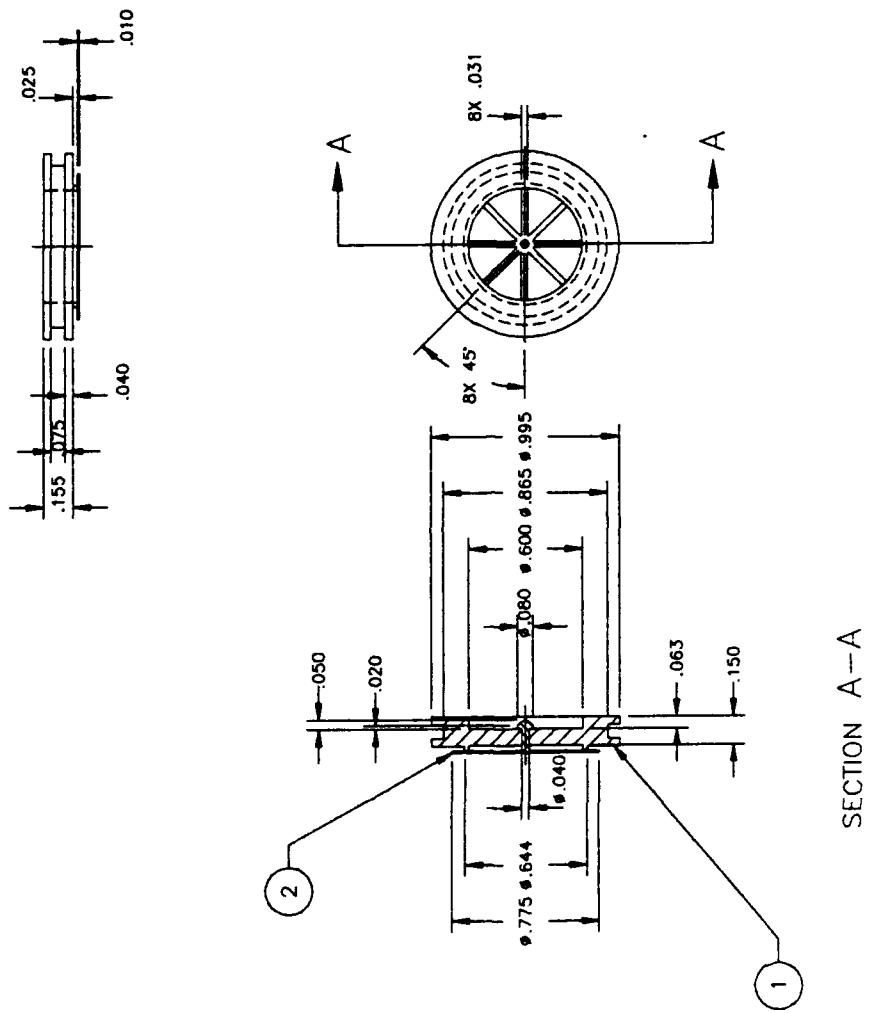


FIGURE 13. INHALATION CHECK VALVE

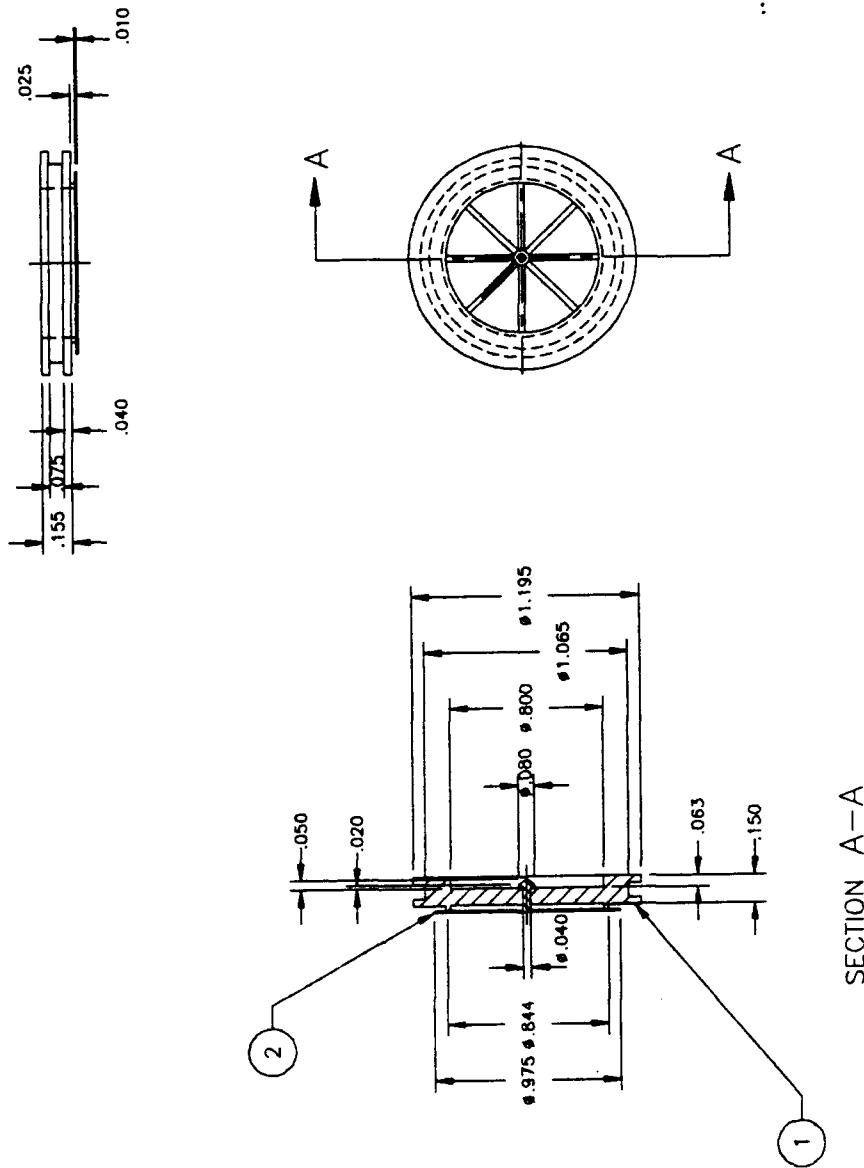


FIGURE 14. EXHALATION CHECK VALVE

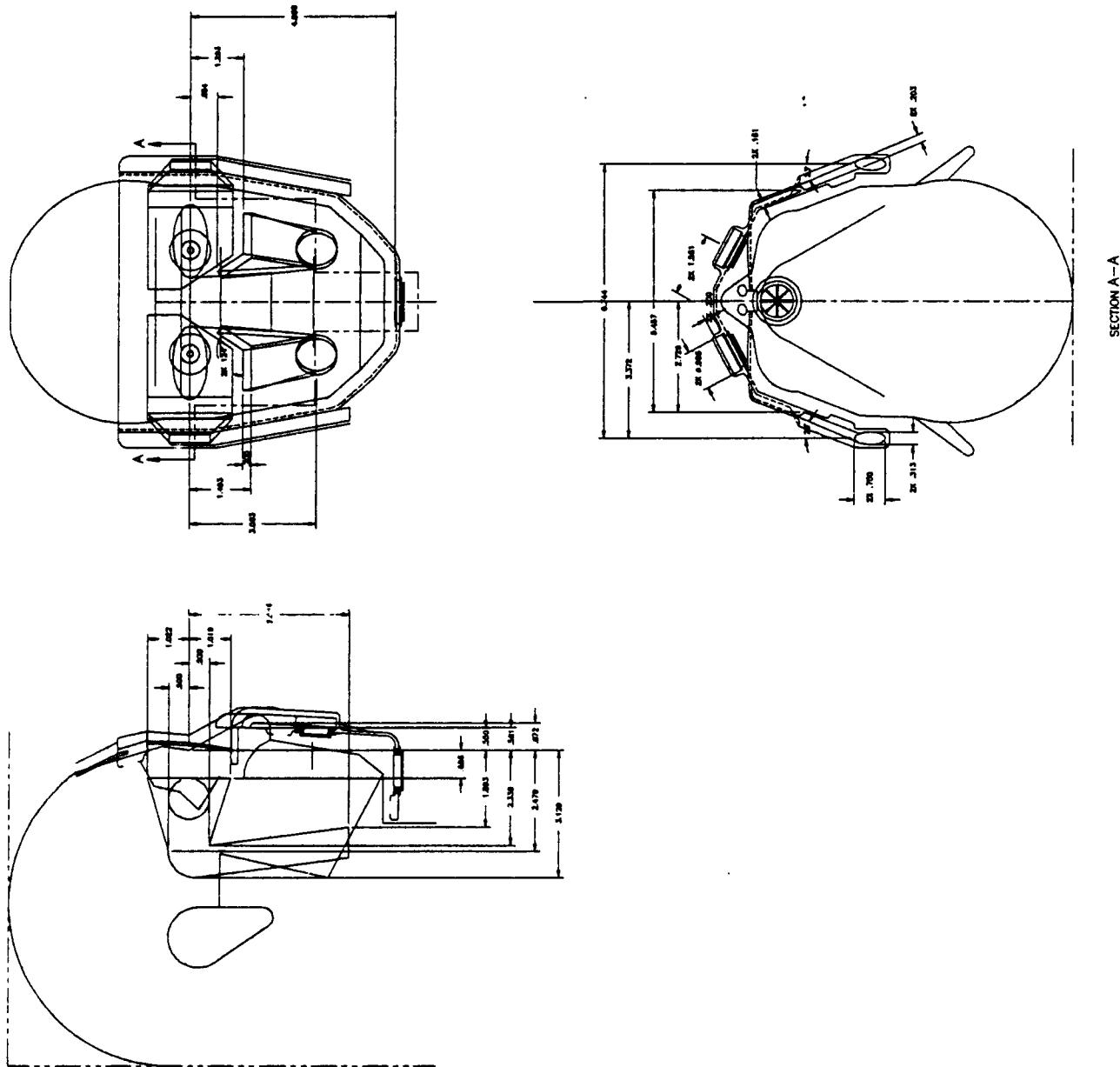


FIGURE 15. AIR LINE CORES

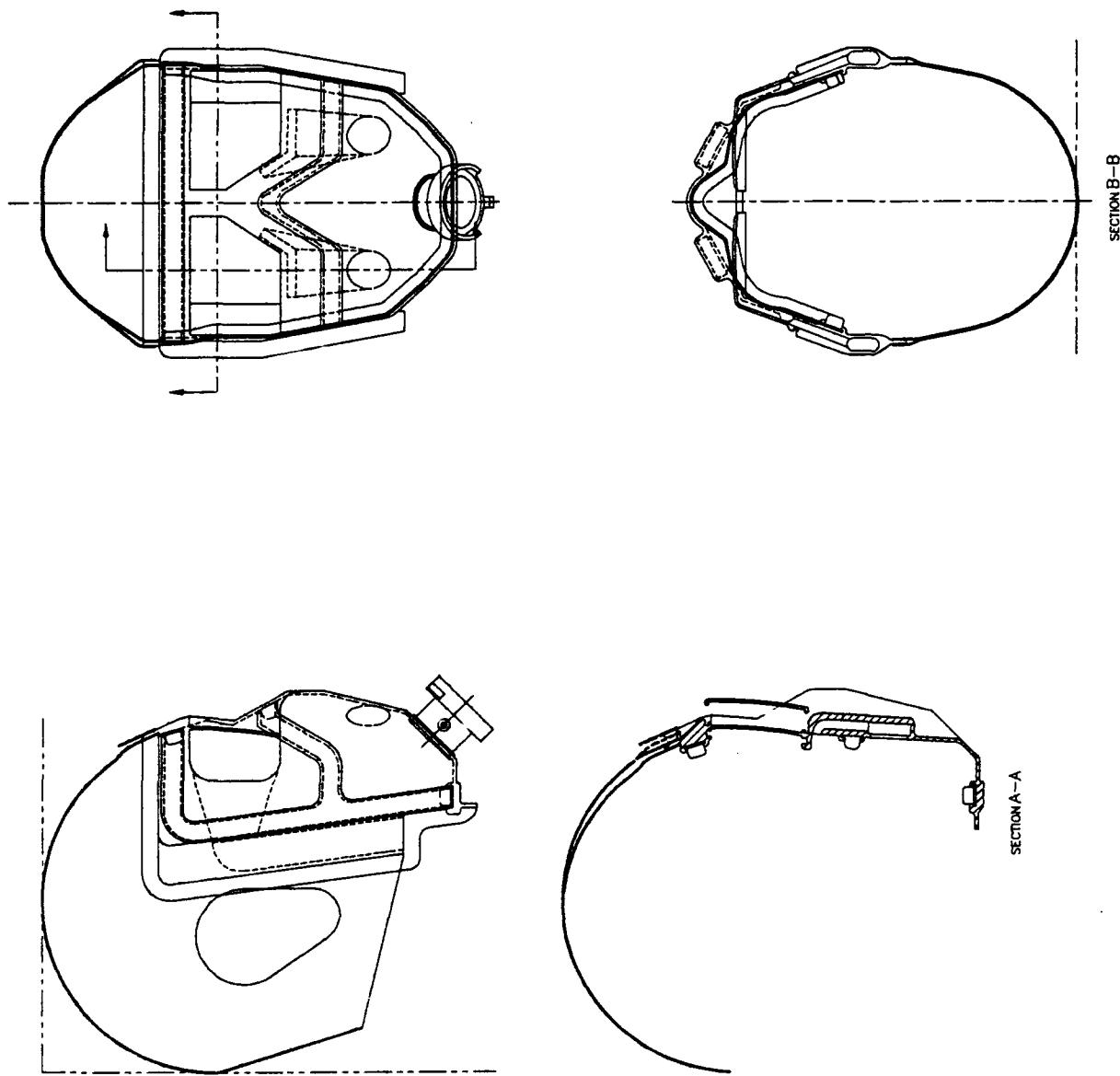


FIGURE 16. FACEPIECE

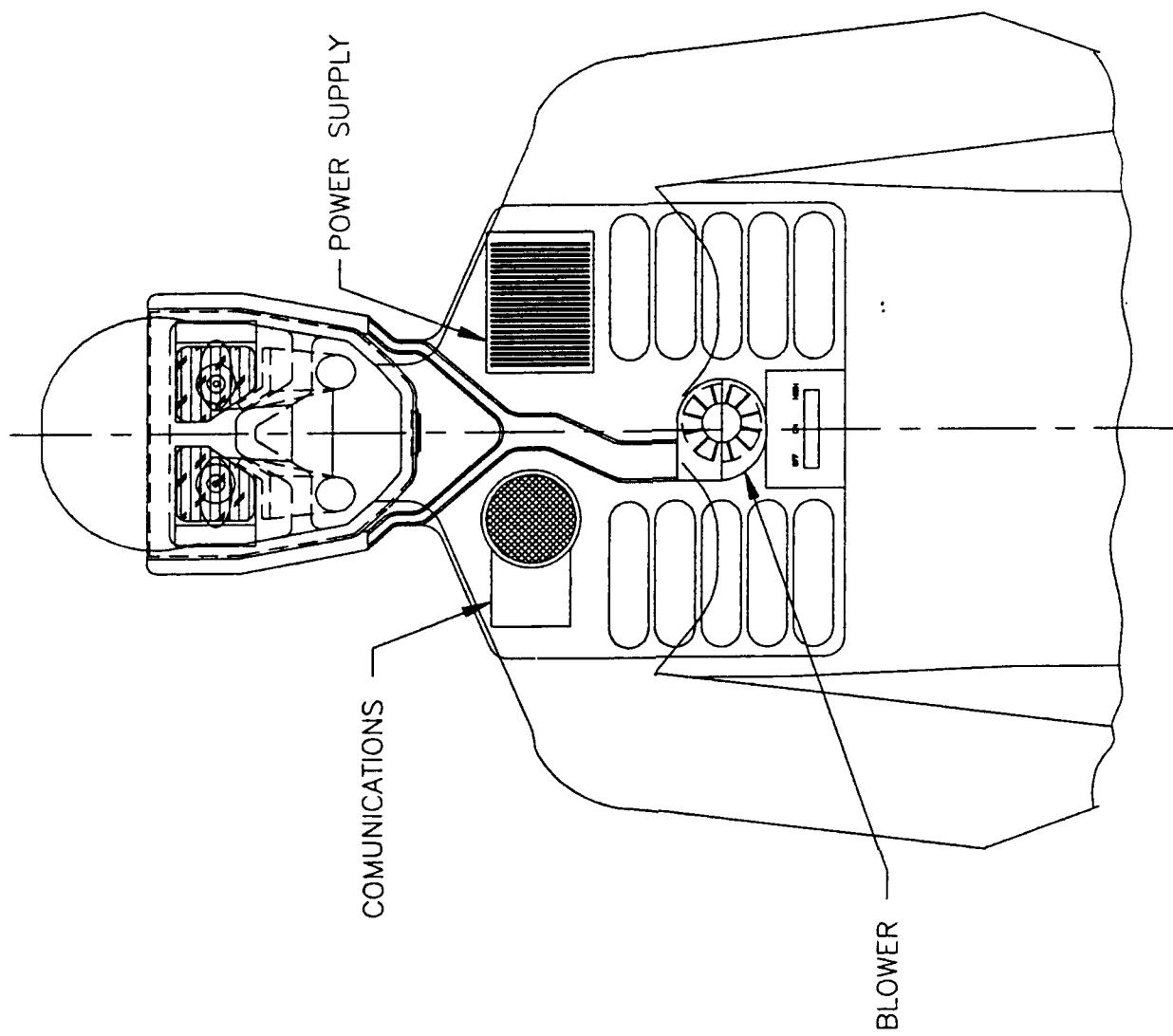


FIGURE 17. MASK ASSEMBLY WITH PRELIMINARY LAYOUT OF ELECTRONICS

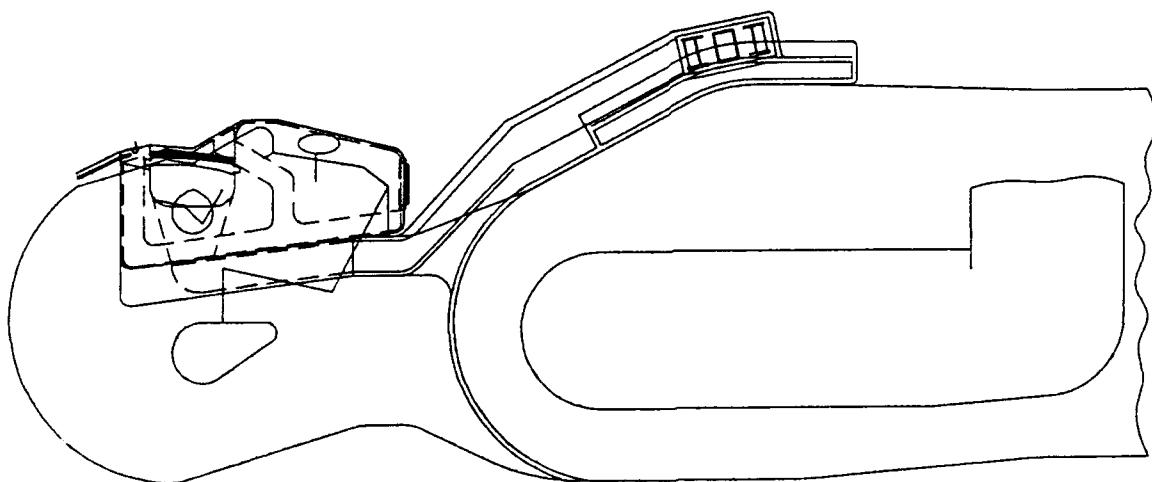
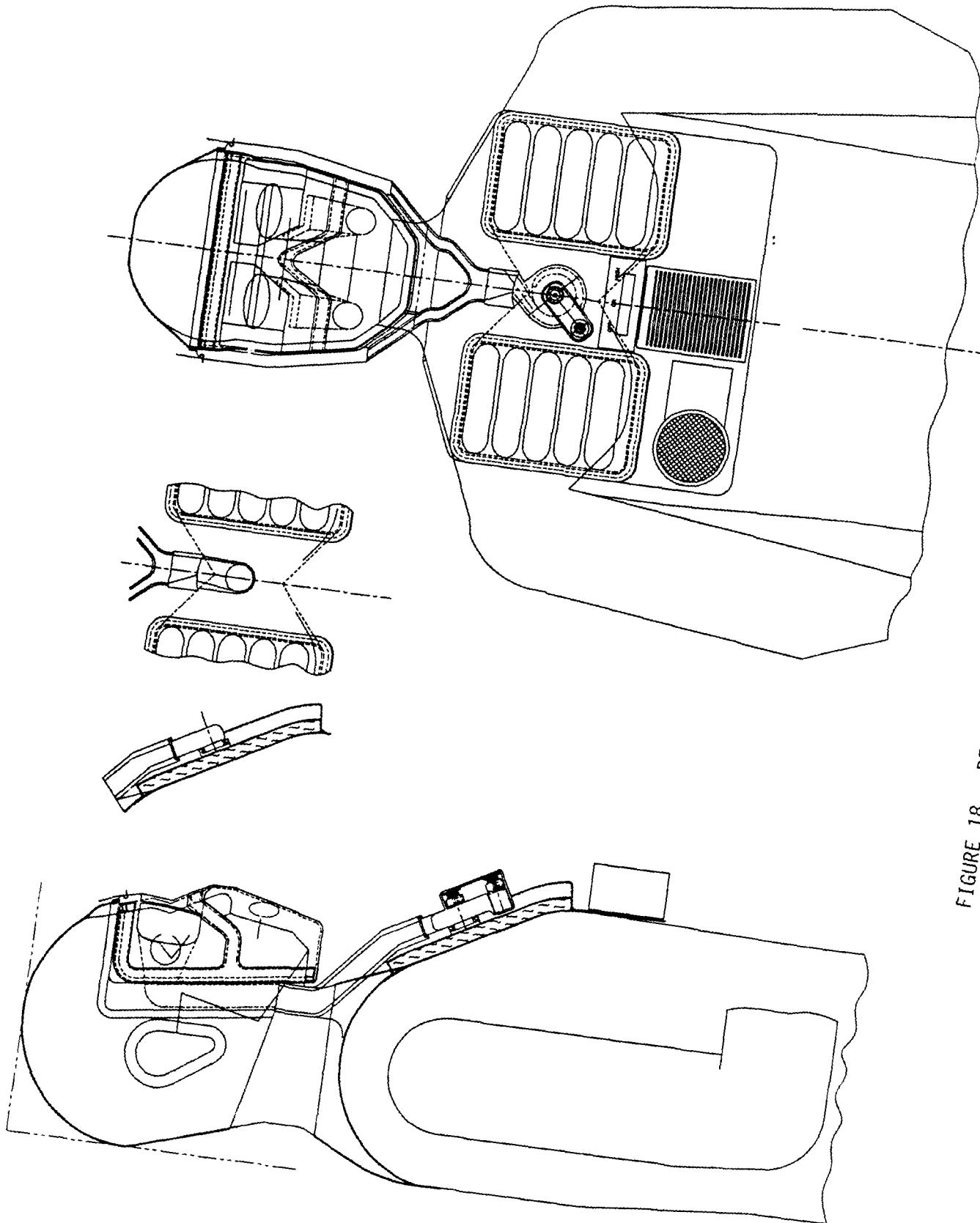


FIGURE 18. REMOVABLE BLOWER CONCEPT



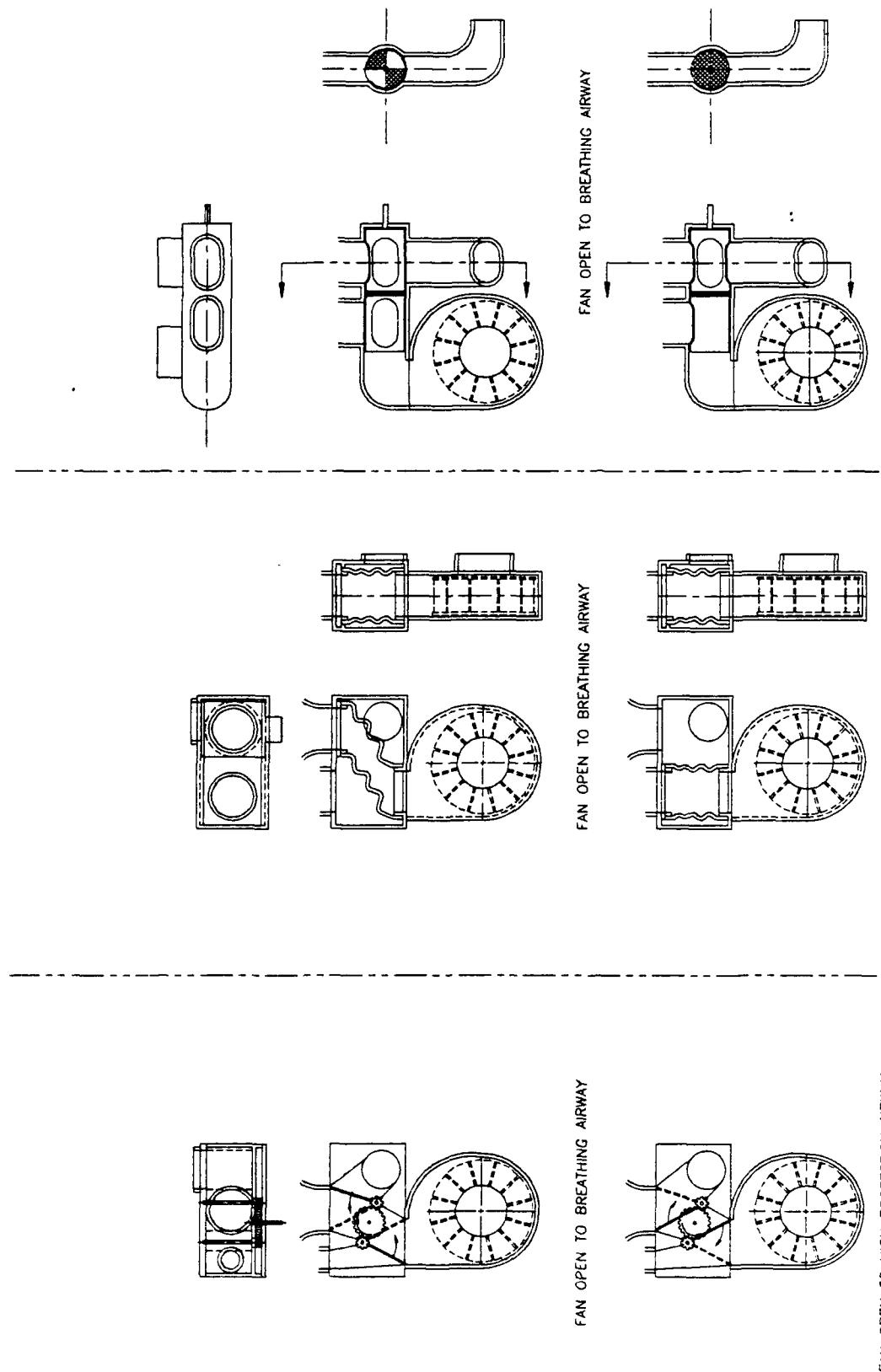


FIGURE 19. CONCEPTS FOR BLOWER WITH HIGH-PROTECTION MODE OPTION

the given pressure drop of the entire mask system. The RESPO 21 Developer's Specification states that the mask system should only have a pressure drop of 30 mm water at 85 lpm, thus at 2 CFM (56 lpm) we should expect an even lower pressure drop. The initial assumption was that, in order to be effective, the blower should be capable of delivering 2 CFM (56 lpm) at 20 to 25 mm water pressure drop.

5.12.8.1.1 Centrifugal

The centrifugal-type blowers that best fit the design criteria for the multi-layer mask was the Sipin blower and a blower made by Micronel. The Sipin blower consists of a custom design intended specifically for the multi-layer mask requirements. Sipin selected the motor and designed an impeller/housing assembly to deliver the desired flow at the anticipated pressure drop. A Sipin blower was promised during the program for use with the multi-layer mask, but was never received.

Micronel, however, offers a line of centrifugal blowers that were readily available off-the-shelf. Micronel also manufactured a line of vane-axial-type blowers that offered certain advantages over the centrifugal blowers. The main problems with the centrifugal-type blowers was how to configure the multi-layer mask to easily change out the blower, and how to reduce the somewhat bulky profile of the centrifugal blower with the motor protruding from the impeller housing as shown in Figure 20.

5.12.8.1.2 Vane-Axial

The vane-axial blower could be easily changed out if not used, and the lower profile available with this blower is much better than the centrifugal-type blower. Figure 21 shows a potential layout with one of the Micronel vane-axial type blowers. Three vane-axial type motors were ordered from Micronel in order to cover the range of possible airflow conditions with the final mask model. These three blowers were models, V241MS-6V, V301MS-6V, and V361MS-6V. The technical data describing the performance of these three blowers is subject to interpretation, but it appears that the resultant pressure drops at 2 CFM for each blower are respectively, 8.9mm, 17.3mm and 30.6 mm.

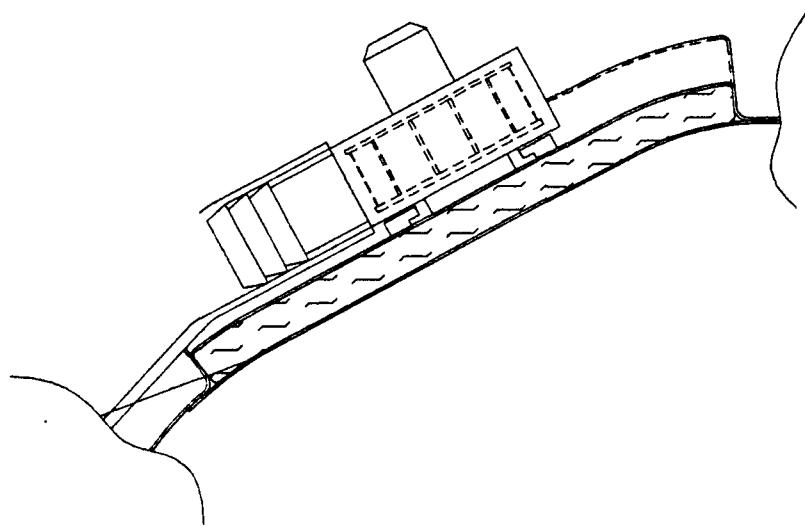
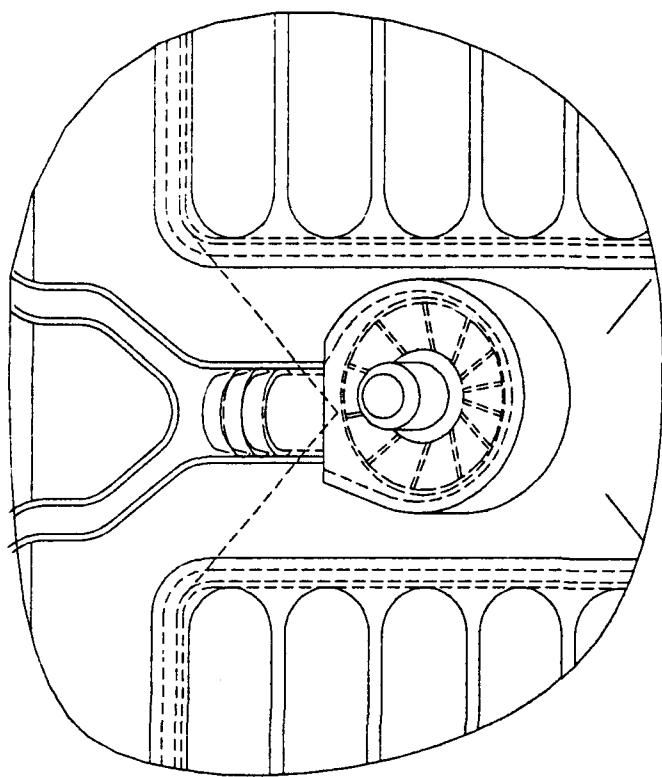


FIGURE 20. CENTRIFUGAL BLOWER, SHOWN POSITIONED
ON HOOD BIB

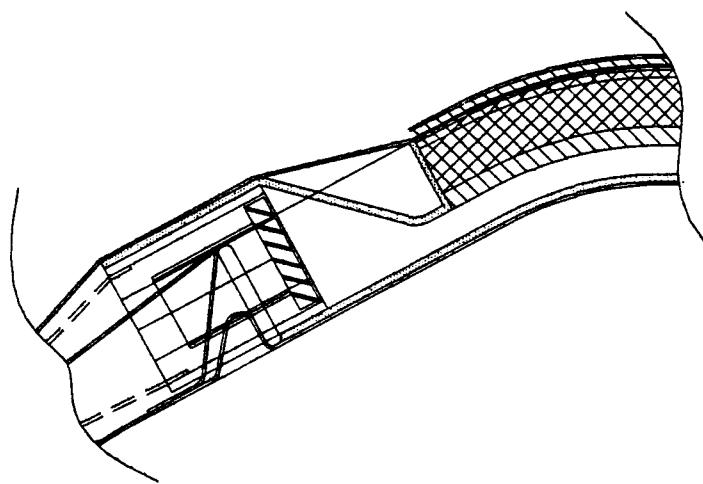
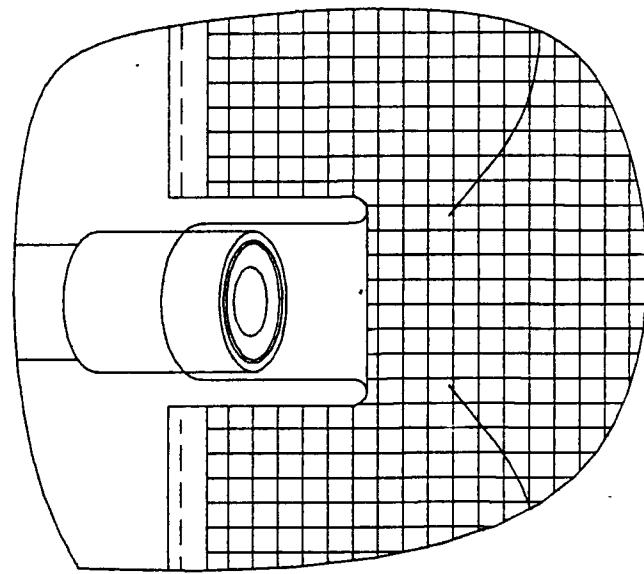


FIGURE 21. VANE-AXIAL BLOWER, SHOWN POSITIONED
ON HOOD BIB

5.12.8.2 Communications

The intelligibility of communications between mask wearers should be enhanced. The RESPO 21 Developer Specification states a requirement of 95 percent comprehension using the Modified Rhyme Test with the subjects 10 feet apart under "normal" conditions. With this requirement in mind, a system was specified that included a microphone mounted inside the multi-layer mask facepiece connected to a speaker attached to the front of the multi-layer mask bib. A power supply and amplifier were also required to transmit and amplify the signal from the mask to the speaker. The system was planned to operate as a portable intercom system.

5.12.8.2.1 Speaker

Several companies were contacted that offered a portable intercom system that was intended specifically for use in a respiratory protection device. The early layouts were based on the size and configuration of the model Loudmouth II voice projection unit manufactured by Earmark. This unit contained the speaker, the amplifier, and the power supply and is thought to be representative of the state-of-the-art in voice projection units. However, at the time of the preparation of this report, an effort being conducted by Battelle for CRDEC titled "Evaluation of Electronic System Concept for Respiratory Protection System 21" is compiling information on speakers and amplifiers for the multi-layer mask. The results of this report should be available by March of 1992.

5.12.8.2.2 Microphone

Many different types of microphones were considered for use with the multi-layer mask. These types include bone conduction, throat, and acoustic microphones. Of all the microphones tested, the acoustic microphones provided the best performance overall. Within the field of acoustic microphones there are electret, balanced armature, and various magnetic microphones currently being analyzed and evaluated for the multi-layer mask. As stated in the section on speakers, the work conducted on microphones is being conducted by Battelle for CRDEC under the program "Evaluation of Electronic System Concept for Respiratory Protection System 21". At this stage it is difficult to anticipate the size and location of the most appropriate microphone

for the multi-layer mask and thus the current layout indicating electronic components omits this component.

5.12.8.3 Power Supply

The power supply will contain the controls and battery power for both the blower system and the communications system. Information was gathered on potential military-type batteries. The option to use commercially available batteries was investigated for increased design flexibility, in the event the multi-layer mask system is used in an area where the military batteries may not be readily available. As before, this work is being conducted by Battelle for CRDEC under the program "Evaluation of Electronic System Concept for Respiratory Protection System 21".

5.12.9 Filtration

A separate program conducted by Battelle for CRDEC titled "Evaluation and Optimization of a Flexible Filtration System for Respiratory Protection System 21" was tasked to evaluate and develop a new filtration system design that will reduce the breathing resistance and the bulk of the current filtration system. The results of the filtration program are being compiled concurrently with the results of this study.

The filtration system was envisioned to be located on the front portion of the multi-layer mask bib. Ducting would be used to connect the facepiece to the filtration system. It was anticipated that the filtration material be replaceable, semi-flexible, low in profile, and low in inhalation breathing resistance.

5.12.9.1 Filter Element

Early in the program, it was decided that the filtration system should incorporate aerosol filtration, gas adsorption media, and an appropriate spacer material into integral filter elements. The filter element was found to require 40 to 50 sq in. of surface area. An early layout of the filter elements incorporated onto the multi-layer mask is shown in Figure 22. The thickness of the filter element was estimated based on the average thickness of some of the filtration media tested early in the program. It was assumed that 48 sq in. would provide a reasonable surface

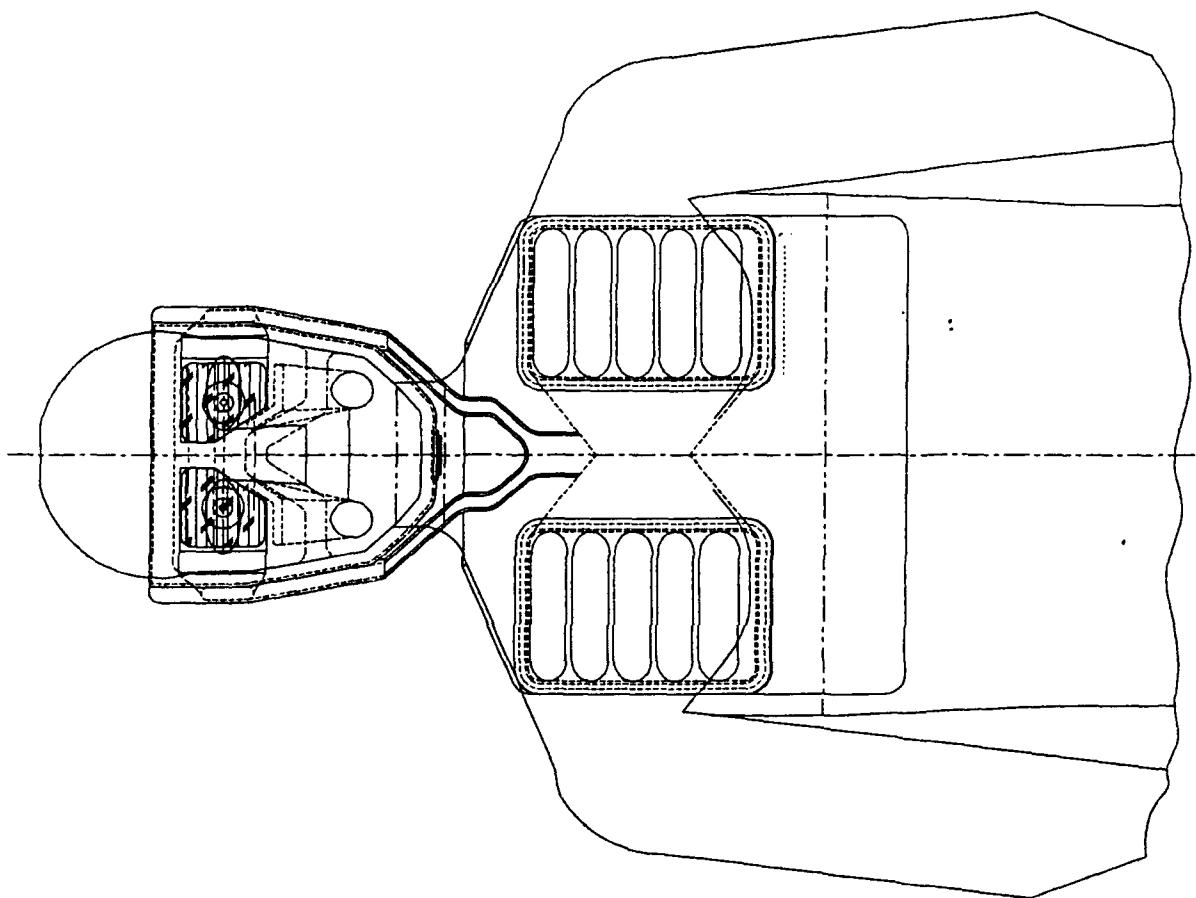
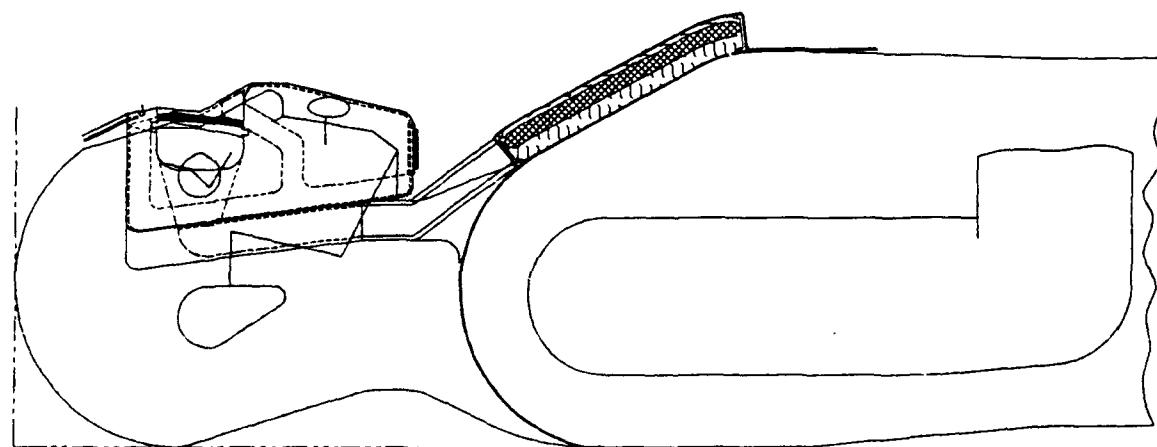


FIGURE 22. FILTER ELEMENTS, 48 SQ IN.



area for the filter elements. It was also anticipated that by utilizing two filter elements, and designing an appropriate valving system, that each filter element could be changed in the field while wearing the mask and breathing through the other element.

5.12.10 Hood

The purpose of the hood on the multi-layer mask is to cover the sides, top and back of the head with chemical agent resistant material. The hood is to be attached to the edge of the facepiece. Since the facepiece is envisioned to be made from an elastomeric material it is possible to insert mold either the rim of the hood itself or an intermediate material that the hood could potentially be bonded to. Different concepts for the hood attachment are illustrated in Figure 23.

5.12.11 Suspension

The purpose of the suspension is to hold the facepiece with faceseal against the contours of the face with sufficient force to maintain an adequate seal. The design or suspension should require little or no adjustment during the donning of the multi-layer mask. The amount of force provided by the suspension is a function of the compliancy and fit of the faceseal. With this in mind, a tentative suspension design was selected to provide a simple means to retain the facepiece (with faceseal) onto the head. Determining the elastic force required of the suspension could most efficiently be done in parallel with the faceseal development.

Since both the suspension and the hood need to be attached to the facepiece, concepts were developed to accommodate this situation. The hood needs to be attached and sealed from contamination completely around the perimeter of the facepiece. The suspension only needs to be attached along the sides and top of the facepiece. For the initial demonstrator model, a suspension design was patterned off of a sample suspension supplied by CRDEC.

5.12.12 Mask Assembly

Integrating all of the above features, the demonstrator model of the multi-layer mask can be shown as it should appear in its assembled form. Figure 24 illustrates an assembly of the multi-layer mask components.

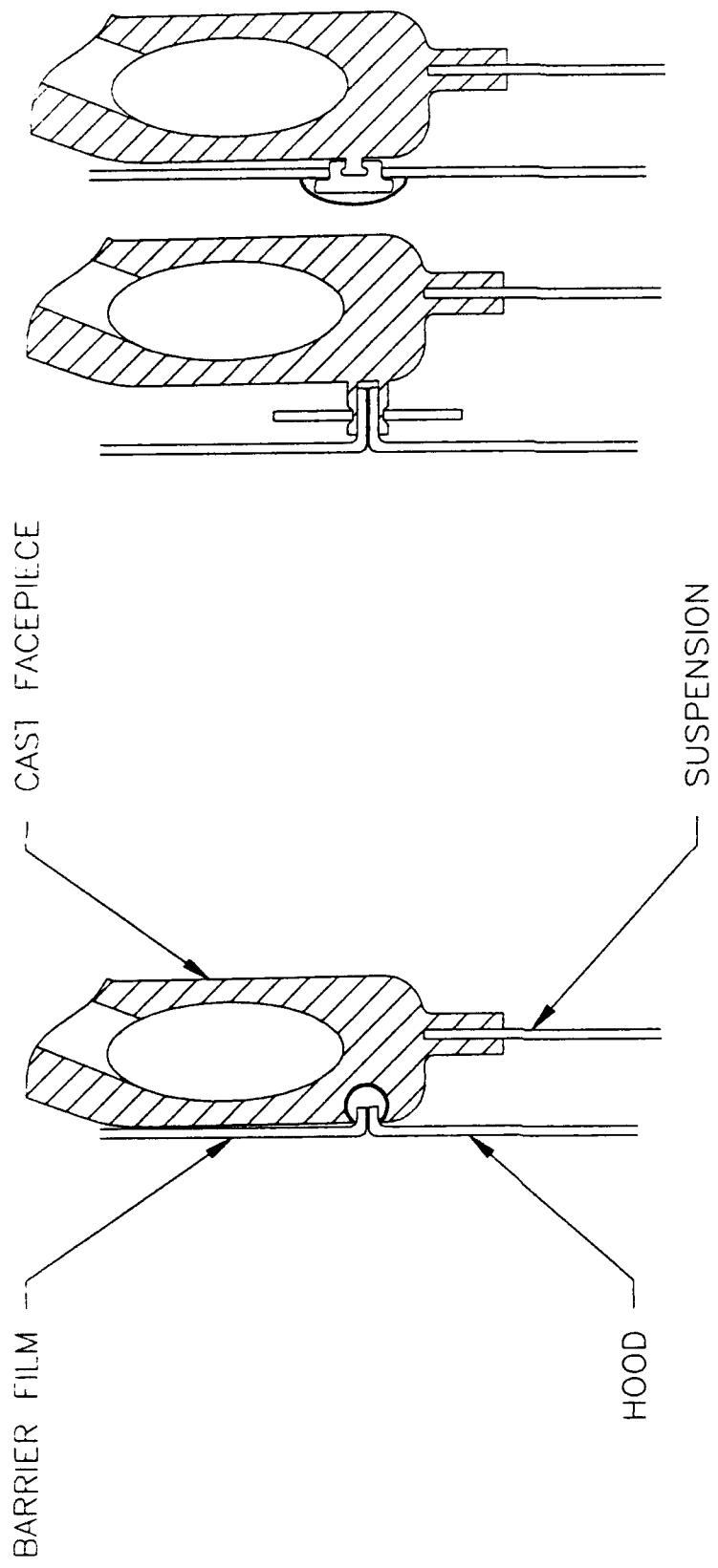


FIGURE 23. HOOD AND SUSPENSION ATTACHMENT CONCEPTS

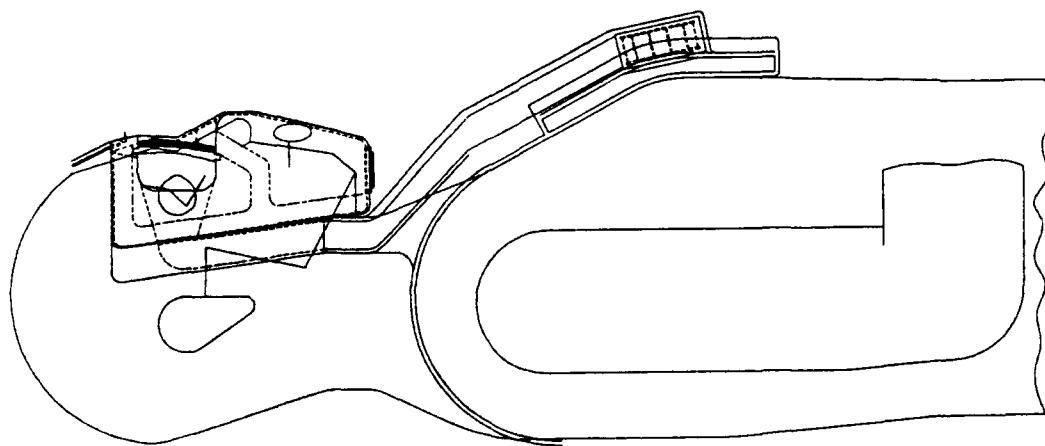
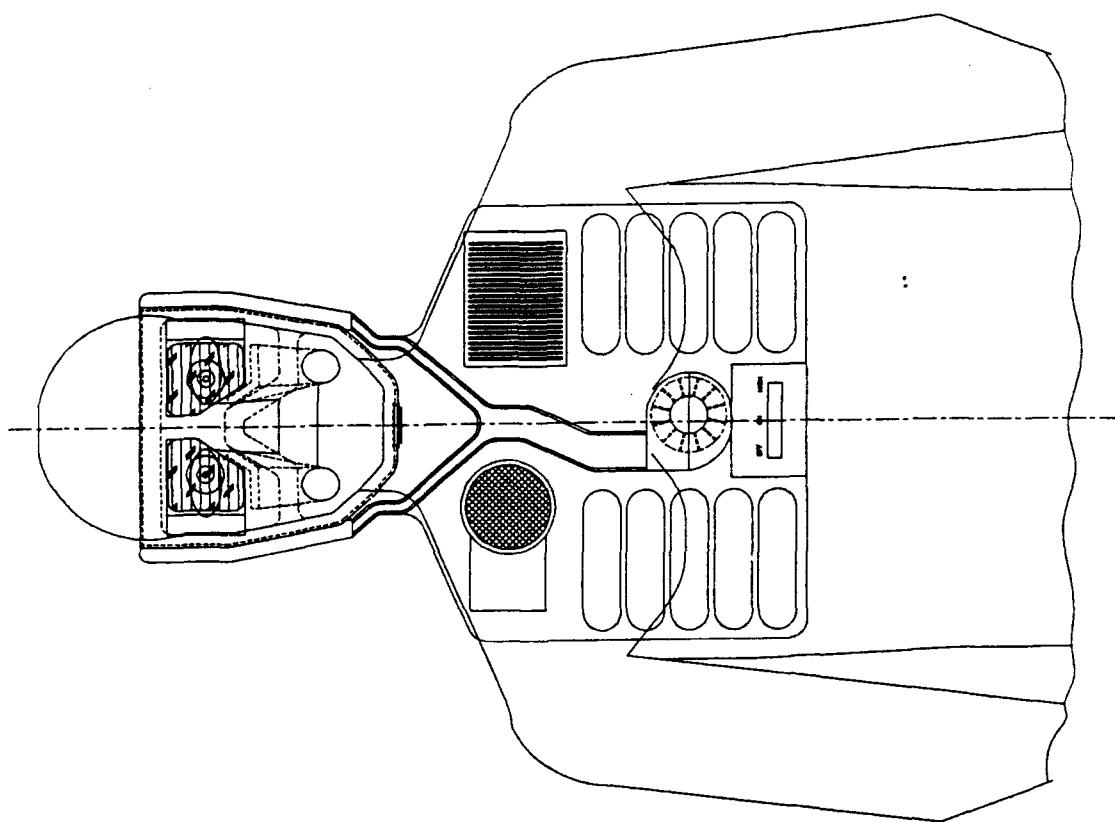


FIGURE 24. MULTI-LAYER MASK ASSEMBLY

5.13 Materials Selection

The most appropriate material had to be selected to model a demonstrator mask for evaluation. It was not always possible to use materials that perfectly fulfilled the intended design requirements, specifically with regard to chemical agent protection. Every attempt was made to select a material that acted and felt like chemical agent resistant material even if it were not chemical agent resistant. Testing materials for chemical agent penetration was not always feasible and in some cases, particularly in the casting of the facepiece and faceseal, a material needed to be selected early in the program to enable the design and fabrication of molds to progress without major setbacks.

5.13.1 Input From Client

In Appendix E of this report is a list generated by CRDEC of components with the candidate materials selected for each component. The list is not definitive, but it includes representative materials that should yield encouraging results.

5.13.2 Criteria for Demonstrators

At this stage in the multi-layer mask development, it was important to generate the design and geometric details to allow for the modeling of three dimensional semi-functional artifacts. The selection of appropriate materials for the final prototype is an iterative process that is constantly changing as new materials and fabrication techniques are being introduced. It was our objective to construct the most representative model conceivable with the current knowledge of NBC materials available and optimize the design in subsequent development phases to better accommodate a potentially more suitable material as they become known or as they are developed.

5.13.2.1 Facepiece

The principal requirement for the facepiece was that it be made from an optically clear elastomeric material that exhibited a hardness of between 40 to 60 Shore A. If the material was

castable, that was considered to be a benefit since it was anticipated that the facepiece would be sculpted by hand, which lends itself well to fabricating inexpensive molds. The candidate material identified by CRDEC for use on the facepiece was an optically clear aliphatic urethane. Another potential material identified for casting the facepiece was an optically clear silicone.

5.13.2.2 Lenses

The lenses include both the corrective lenses and the protective lenses. Since the materials of the lenses were required to be optically clear, shatter resistant, fog-free, and scratch resistant, the natural choice was polycarbonate. Polycarbonate is a commonly used material for safety glasses and can be coated to enhance scratch resistance, minimize fogging, and protected from chemical agents.

5.13.2.3 Hood

The main requirements for the hood material are to be chemical agent resistant, supple and drapeable, and relatively noise free (to minimize rustling). It was very difficult to find chemically agent resistant material that was not relatively stiff and unsuitable for hood fabrication. Some of the chemical agent resistant materials that were drapeable enough for the hood didn't always test as high as the RESPO 21 Developer's Specification for chemical agent resistance (24 hour liquid exposure without breakthrough). Often times it was difficult to communicate to laminators what physical properties were required to enable fabrication of an acceptable hood. In order to proceed with the demonstrator model, a readily available urethane coated nylon pack cloth was selected for the hood. The nylon pack cloth closely resembled some of the more encouraging candidate materials we encountered during the program.

5.13.2.4 Filtration

Since the filtration evaluation task was conducted in parallel with this program, it was difficult to speculate as to what the recommended filtration media would be. The surface area of the filtration media was specified to be 40 to 50 sq in., but the thickness was to be determined by the filtration evaluation task. Initially we assumed that the thickness of the filtration media

would not exceed 1 inch. Sample pieces of filtration media were supplied to us throughout the program.

5.13.2.5 Barrier Film

The barrier film is intended to be a thin sheet of chemical agent resistant material that would fit over the outside surface of the facepiece. The barrier film is not intended to cover the lens area of the facepiece, but the film must couple with the protective lenses that are also chemical agent resistant. The requirements for the barrier film are for it to be chemical agent resistant, transparent, and relatively flexible in thin sheets. In order to match the outside geometric surface of the facepiece, it is necessary to vacuum thermoform the material for the barrier film into the appropriate shape. Thus, the barrier film material needs to be thermoplastic. A candidate material for the barrier film is a fluoropolymer (FEP).

5.13.2.6 Faceseal

The initial intended design for the faceseal is based on a previous study conducted by Battelle for CRDEC to develop and evaluate novel seals for RESPO 21. The results of the novel seal study identified a dielectric silicone gel as a potential faceseal material. A suitable material was needed to encapsulate the gel. This material needed to be stretchy (like rubber), thermoplastic, heat sealable, and available in thin sheets.

One of the potential materials recommended by CRDEC for the faceseal was Kraton. Kraton exhibited all of the properties desirable for use as the encapsulating media. Kraton was also available in a variety of compounds and thus would be flexible enough to allow the material to be selected to suit the specific design needs.

5.13.3 Selections Made

The material selections had to be made as early in the program as possible. In particular, for the mask components that require special fabrication techniques such as the cast facepiece, early material selection was required to enable the work to proceed on the subsequent tooling

required that was appropriate for the specific material. Alternative materials could easily be substituted as needed after the components were fabricated and evaluated.

6.0 FABRICATION OF THE PROTOTYPE

6.1 Establish Procedure

The fabrication procedure focused primarily on the facepiece/faceseal assembly. The facepiece is the hub of the multi-layer mask assembly. Since it was important to accurately fit the mask to a human face/head, it was necessary to start the modeling of the components that were in the direct contact with the face. This component was the facepiece/faceseal assembly.

After reviewing the design with a sculptor and moldmaker skilled in designing and fabricating masks, a core and cavity molding procedure was selected as the fabrication technique. The core would be a sculpted form with removable inserts that would establish the inside surface geometry of the facepiece. The cavity would form the outside surface geometry of the facepiece. Combining the core and cavity would result in a void space that would essentially be the facepiece. Ports are machined into the assembly which permits casting the elastomeric material and venting the entrapped air. After curing the cast material the core and cavity are separated, the inserts are removed, and the facepiece is completed. This is the basic procedure that was followed to obtain an elastomeric facepiece.

6.2 Generate Basic Headform

In order to begin layout of the facepiece/faceseal assembly, it was necessary to develop and fabricate a basic headform that was representative of the 50th percentile male anthropometric data that was used for the detailed design. The simplest way to obtain an accurate, representative headform is to make a cast replica of the face of an average size male. The replica did not have to fit the anthropometric data exactly since the drawings served essentially as guidelines for the sculpted details. After measuring face dimensions on several male Battelle staff members, one was found that closely matched the 50th percentile male anthropometric data.

For purposes of sculpting a facepiece for the multi-layer mask, the headform should include from the top of the head to just below the Adam's apple and from ear to ear. For the

modeling purposes on the multi-layer mask it was not necessary to have a complete bust. Based on these assumptions, a headform replica of the selected staff member was cast.

First, the subject was prepared for the replication by covering the hair on the head with a bald wig piece and applying petroleum jelly on the eye brows to facilitate release of the replicating material. This particular casting was done with the subject's eyes and mouth closed. While the casting was setting up, the nasal passages were kept clear for breathing. The replicating material is called Algi-Cast made by Tri-Ess Sciences, Incorporated, in Burbank, California. The Algi-Cast is a powder derived from seaweed (algae) which, when mixed with water, gels into a rubbery substance. A batch of Algi-Cast was mixed with water and carefully spread onto the subjects face, making sure not to entrap air and trying to cover as much of the detail as possible. The subject's eye were closed and the nasal passages were kept open. The whole area was covered with Algi-Cast and small pulls or handles were formed on the surface.

The Algi-Cast dries to a rubbery, very flexible material and will not hold its shape unless it is backed with a more rigid material. The most suitable material for this is fast-setting medical plaster bandages, sometimes used in combination with plaster. After the Algi-Cast sets, a plaster mixture was prepared and applied over the Algi-Cast around the formed pulls or handles. After a layer of plaster is applied, the final layer was finished with quick setting plaster bandages. When the plaster has set, the casting was slowly removed and the results were examined.

Algi-Cast is an organic material that breaks down eventually so it is necessary to preserve the replication in a more permanent material. Therefore, a positive was cast into the Algi-Cast mold using gold dental stone with strips of burlap for reinforcement. The results of the dental stone headform casting were acceptable leaving only some minor dressing of the surface and reconstruction of the ears. The cast dental stone headform is shown in Figure 25. The headform casting was then used to generate a master mold out of a urethane called P.U.R.E. 1040 made by Perma-Flex Mold Company in Columbus, Ohio. Since the urethane is flexible it needed to be backed up with a plaster shell.

6.3 Sculpt Facepiece Geometry

The sculpting of the inside geometry of the facepiece could then proceed. The faceseal was laid out on the headform to locate the facepiece.

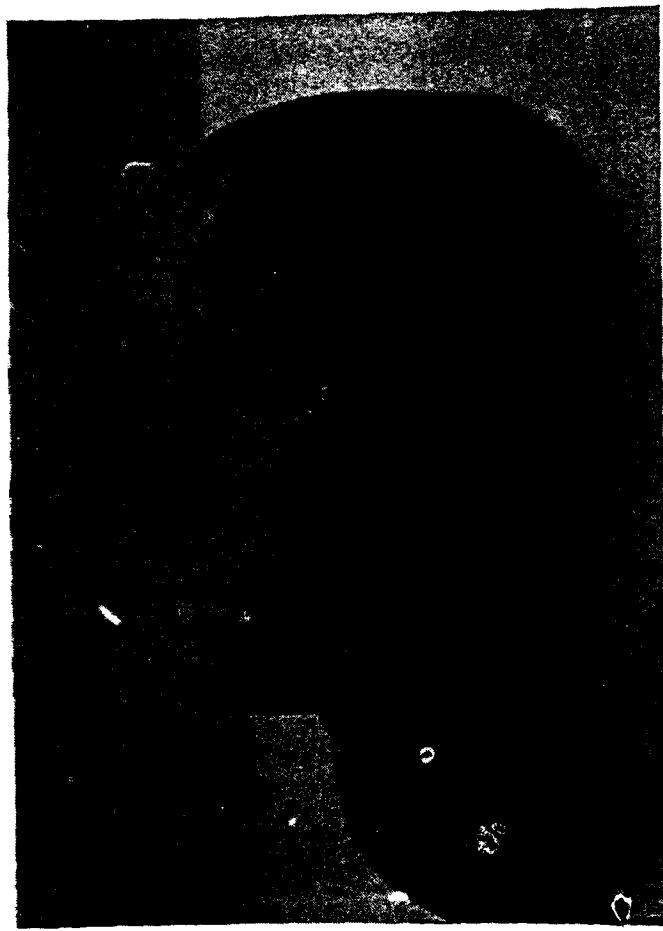


FIGURE 25. CAST HEADFORM

6.3.1 Face seal

The face seal is a constant cross-section throughout its length. The best way to fabricate this constant cross-section was to extrude a length of material, layout the extrusion onto the headform according to the detailed design, and join the extrusion together to complete the periphery and connect the piece that crosses the nose. An extrusion template was fabricated using the cross-sectional shape of the face seal. A soft, workable modeling clay called Kleen-Klay distributed by Art Chemical Products in Huntington, Indiana, was extruded through the template to yield lengths of face seal material. These lengths were positioned onto the headform and joined together forming one continuous ring of seal with a length crossing the nose and junctioned into the sides of the seal.

A material was needed to cast around the clay face seal that was flexible yet strong. A high strength HSII RTV silicone made by Dow Corning was selected to cast a mold of the face seal. By combining the silicone mold and a headform, a face seal could be cast out of an epoxy material, FR6301/5235M made by the Fiber Resin Corporation. The rigid epoxy face seal was positioned onto the bare headform to continue sculpting of the facepiece.

Since it was desirable to sculpt the inside surface of the facepiece, and since the facepiece was designed with a track to retain the face seal, then it was necessary to sculpt the outside surface of the track around the retaining flange on the face seal. This was accomplished by adding Kleen-Klay around the edges of the epoxy face seal until it was flush with the flanged back edge. A small tool was made that would carve-out an L-shaped slot in the clay surrounding the face seal flange. The L-shaped slot provides the retaining geometry for the face seal. With this geometry intact, another casting was made in urethane of the headform with the face seal and retaining slot. A material call Hydrostone distributed by the Hamilton Parker Company of Columbus, Ohio, was used to cast the positive from the urethane mold.

By using the rigid epoxy face seal as a pattern, a split mold was made for casting solid elastomeric face seals. The high strength silicone was used for the mold material and the parting line was placed on the back side flange of the face seal. Using the split mold, solid elastomeric seals were cast. Materials used for the elastomeric seals include P.U.R.E. 1040 urethane, high strength silicone, TC-620 low-durometer urethane made by BJB Enterprise Incorporated of Garden Grove, California, and PVC "worm rubber" manufactured by M.F. Manufacturing Company Incorporated of Fort Worth, Texas. A variety of hardnesses of elastomeric seals were cast for comparison.

6.3.2 Lens

Using the dental stone positive of the headform with the face seal and retaining slot as a base, the corrective lenses could then be fabricated and positioned.

6.3.2.1 Optical Correction

The shape of the optical corrective lenses were determined from the detailed design layout and is shown in Figure 7 from Section 5.12.2.2. The corrective lens shape was designed to allow as much field-of-view as possible yet not interfere with the edges of the face seal and the lens area to mouth/nose cup air lines. The early lens design shows a lens that is very geometric in shape, and utilizes tabs machined into the lens to help retain it in the facepiece. Consultation with optometrists indicated that the lens design may present problems for grinding prescribed curvatures, that is, it may be difficult to grind the non-standard lens with tabs. After considering the options, we decided to find an existing lens, similar in shape to our lens design, and fabricate an individual frame for each lens. Each frame would be designed with tabs to allow placement into the facepiece. The frames could be common for all masks and thus standard corrective lenses could be ground for each individual.

In order to use this lens/custom frame approach in the model, without having to sculpt and mold a custom frame, it became necessary to find an existing frame for the lens shape and modify the frame for our design. The frame was selected from a local retail optical center, was fitted with the lenses, and ground down to resemble the design in Figure 26. Tabs were cut out of flat pieces of acrylic and bonded to the edge of the frames. The lenses with frames were positioned onto the head form by locating the center of the lens over the center of the eyes. The lenses were placed with a stand-off distance of approximately 14 mm (0.55 inch). Clay was used to fill in the void space behind the lens and provide support for the lens.

6.3.2.2 Air Passageways

The designed shapes for the air passageways are shown in Figure 27. These shapes need to be made as removable inserts to be positioned onto the inside facepiece geometry side of the facepiece mold. Based on the designed shapes, details were generated that described the airlines as machinable pieces. For consistency, machined air line inserts were used since they would

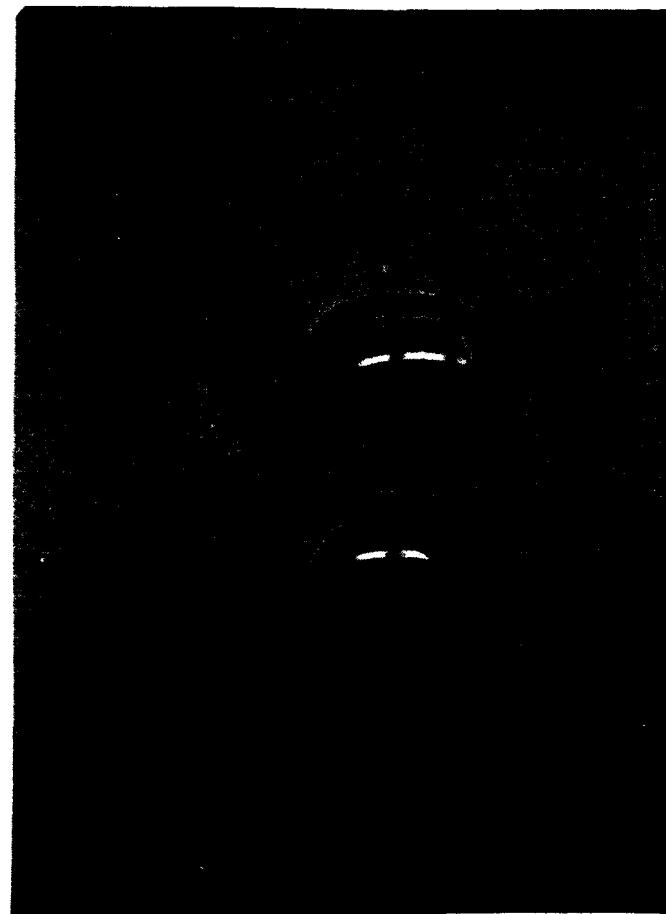


FIGURE 26. CORRECTIVE LENS INSERTS

yield more accuracy than hand sculpted inserts. After machining the air line pieces and assembling them, and then fitting them to the facepiece it was discovered that the machined shapes were too rigid to implement into the model. Instead, the shapes were used to fabricate compliant air line inserts that could better follow the contours of the headform. The compliant air line inserts were cast from the high strength silicone with bendable wires cast in the middle. This allowed the air lines to form along the contours of the headform.

After a shape was determined for the air lines that was acceptable, molds were prepared around the compliant air lines. After the facepiece casting was made, the air line inserts could either be pulled out and re-used or crumbled for easy removal. The air line inserts were made out of brittle, easy to break dental stone, with the hopes that if they could not be removed in one piece, they could be broken into smaller pieces for removal.

With the air line inserts cast from dental stone, the air lines were located on the headform. By design, the air lines direct the filtered air into the lens area, and out of the lens area into the mouth/nose cup area. The lens area and mouth/nose cup area had to be built up with clay and ledges or contact areas sculpted into the clay where the air lines would connect. For the air lines that connect the lens area to the mouth/nose cup area, check valves were positioned as well. At the connection points an effort was made to sculpt locators that would accurately position the air lines for each casting. With the lens area and mouth/nose cup area clayed-in, the air line inserts were placed into position. At this stage, the void space that was desirable between the inside of the facepiece and the headform was filled in with clay.

6.3.3 Void Space

Void space was sculpted in certain areas between the facepiece and the headform to prevent the facepiece from contacting the nose and the mouth. Also, void space provided a means with which to insure that the facepiece contacts the headform via only the faceseal. This is essential to insure an adequate seal when the mask is securely positioned on the users head.

6.3.4 Check Valves

In order to maintain an even, constant airflow throughout the multi-layer mask, and to keep the size and profile to a minimum, check valves were designed and fabricated to suit the requirements. The check valves were made as thin as possible and were based on the shape of

the valves currently used in the M40 mask. The cross-sectional area of the valves were matched with the area of the air lines. Prototype check valves were fabricated out of acrylic and assembled with a thin sheet of readily available latex. If these check valves proved successful, it was anticipated that more suitable materials would be selected for the design. For example, nylon could possibly be used for the valve body and silicone for the membrane. With the valves designed and fabricated, solid aluminum blanks were machined for our sculpting. The check valve blanks were positioned on the headform on the mouth/nose cup area void space.

6.3.5 Facepiece, Inside Surface

With all of the features sculpted on the headform describing the inside surface of the facepiece, it was necessary to carefully remove the air lines and cast a urethane mold of the clayed-up headform. To support the flexible urethane prior to casting the urethane, a plaster mother mold was fabricated. The plaster mother mold was made by surrounding the clayed-up headform with bubble wrap to provide the needed void space for the urethane. Plaster and plaster bandages were applied completely covering the bubble wrap. Figures 28 through 31 show the procedure for plastering. Once the plaster dried, the plaster shell was split and removed from the bubble wrap. The bubble wrap was carefully removed and the plaster shell was positioned around the casting and sealed with clay. Pouring and venting ports were drilled into the plaster shell. A two-part urethane (P.U.R.E. 1040) was mixed together and poured into the void space between the plaster shell and the clayed-up headform. After the urethane was allowed to cure, the plaster shell and the urethane mold were separated from the clayed-up headform. From the urethane mold, a dental stone positive was cast which provided the core for the final casting of the facepiece.

6.3.6 Facepiece, Outside Surface

With the inside surface intact, clay was added onto the core headform over top of the inside surface geometry to create the outside surface of the facepiece. This step implied that the wall thickness and shape of the finished facepiece were determined. The wall thickness at the lens area was assumed to be approximately 0.06 inch thick, while the rest of the mask could increase to 0.09 to 0.12 inch thick. Our intention was to make the mask conservatively strong to



FIGURE 28. BUBBLE WRAP ON SCULPTURE



FIGURE 29. COVERING BUBBLE WRAP WITH
LAYER OF PLASTER



FIGURE 30. COVERING BUBBLE WRAPPED SCULPTURE COMPLETELY WITH PLASTER



FIGURE 31. WRAPPING PLASTER LAYER WITH PLASTER BANDAGES

survive rough handling and support the faceseal. The wall thickness could be optimized on subsequent design revisions.

Another area of concern when generating the facepiece outside surface was how to blend features together without adding extraordinary amounts of material. An even wall thickness was maintained, as much as possible, and the outside of the facepiece was allowed to take on whatever shape it may. This resulted in a somewhat bulbous, bulky configuration which could be minimized in subsequent models.

6.3.7 Attachment Means

For the initial multi-layer mask facepiece, the attachment means for the hood and the suspension was kept simple and flexible to accommodate different materials as they become available. Early on the program, a few concepts were developed that demonstrated potential options for attachment depending on the type and thickness of materials selected. For the first model, a flap or rim was sculpted on the peripheral edge of the faceseal that would allow enough clearance to sew on a candidate hood and suspension.

With the completion of the outside surface sculpture, a urethane mold was cast of the clayed-up headform. This mold would then be used as the cavity for the facepiece casting. In order to preserve the geometry of the outside surface, a stone positive was cast into the urethane cavity. Figures 32 and 33 show the core with inserts and the cavity with a stone positive. With the core, cavity, and inserts prepared, the first facepiece could be cast.

6.4 Cast Facepiece

The core, cavity, and air line inserts were assembled to check for interference and examine the mold for candidate pouring and venting ports. The elastomeric resin was introduced through the high point of the mask which was the nose. The vent ports were added to the corners of the lens area and at the tops of the check valves on the cheeks of the mask. The theory was that the material would be injected by means of a large syringe into the assembled mold through the nose area and allowed to force the entrapped air out of the vent ports. When the injected material started to flow out of all of the vent ports it was assumed the that mold was full of material and virtually void free. In addition to the ports, it was necessary to build onto the

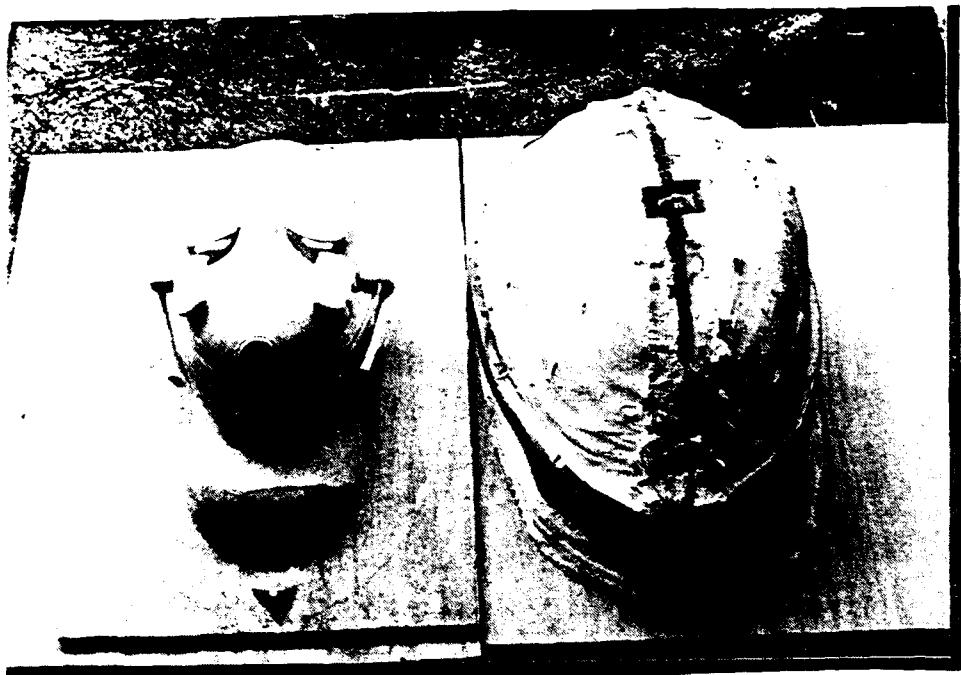


FIGURE 32. CORE MOLD WITH AIR LINE INSERTS
AND PLASTER MOTHER MOLD



FIGURE 33. PLASTER MOTHER MOLD AND CASTING OF
CAVITY SHOWING OUTER SURFACE OF
MASK

mold small reservoirs surrounding each port to allow material to flow out of the ports and fill through the ports as air bubbles work their way out.

6.4.1 Casting Materials

Ultimately, the facepiece was cast from an optically clear elastomeric material. The candidate choice was an aliphatic urethane. A company by the name of Conap, Incorporated, in Olean, New York, was located to provide this material. Conap manufactures aliphatic urethanes in a range of durometers from 60 Shore A to 50 Shore D. The materials selected were the Conoptic elastomers DPTU-10391 and DPTU-10397 which were 60 and 80 Shore A hardness respectively. Since part of the assembled mold, the cavity, was made from a urethane, the mold configuration was tested with an optically clear silicone material first. If the mold configuration yielded acceptable results, the cavity, core, and inserts would be replicated with a material suitable for casting the aliphatic urethane.

Several optically clear silicones were located and two were selected. These were KE 105 made by a Japanese company called Shin-Etsu, distributed by Medford Silicones in Medford, New Jersey and RTV 615 made by General Electric.

6.4.2 Vacuum Chamber

Since the air bubbles and voids should be minimized in the facepiece casting, and stirring or mixing the elastomers prior to injecting introduces air into the mix, a vacuum chamber was required to draw out the air from the elastomeric material. Not only should the mixed pot of elastomeric material be evacuated, but also the entire mold after it has been filled with material. The mold loaded with material should be observable in the event any leaks occurred around the seams of the assembled mold. A vacuum chamber was designed and fabricated that was large enough to accommodate the assembled mold and was made out of thick-walled acrylic so that the mold could be observed during the evacuation procedure. The vacuum chamber was made with a removable lid for easy access and tubing ports to connect to a vacuum pump and a valve for venting purposes.

6.4.3 Elastomeric Resin Injector

The estimated amount of material required for a facepiece was about 600 cc. In order to allow for overflow, reservoirs, and flash, 1200 cc of material was prepared for each casting. Since, to minimize air bubbles, the material was injected into the mold in one continuous shot, a device was obtained that could hold in excess of 1200 cc and inject it into the mold. An injector was designed and fabricated from PVC tubing that could accommodate the amount of material for our casting. A tip from a commercially available caulking tube was used at the end. The plunger was fabricated from a pair of large washers secured loosely around a rubber disk attached to the end of a threaded rod. A handle was added to the end of the plunger to facilitate pushing the threaded rod. The injector looked and functioned like a large syringe. It could be disassembled for cleaning and re-use.

6.5 First Casting

In preparation for casting, the surfaces of the core, cavity and inserts were coated with a mold release. The mold release used for the silicone material was a mixture of 20/80 by volume of beeswax to toluene. This mold release was brushed onto the mold surfaces and allowed to dry. The inserts were bonded to the core with a light coating of cyanoacrylate adhesive called "Wonder Bond" made by Elmer's, and the core and cavity were assembled and sealed at the parting line. Kleen-Klay was pushed into the seams between the core and the cavity to help seal the mold.

The KE 106 Shin-Etsu silicone was prepared by mixing the resin and catalyst together in a clean polypropylene container. The mixture was placed into the vacuum chamber and pumped down to approximately 27 inches of Hg. Initially the material would foam, but after repeated cycles of turning the vacuum on and off eventually the foam subsided. At this point the silicone material was added to the injector and slowly injected into the prepared mold until material began to flow out of the vent ports. Attempts were made to chase the trapped air bubbles out of the mold by back filling through the vent ports using a small syringe.

Although there was no information provided with the KE 106 Shin-Etsu material regarding curing, by conducting tests with sample batches it was found that cast samples could be handled with a cure time of 24 hours at room temperature (25 °C).

After 24 hours, the mold was disassembled and the results were observed. However, the silicone had not quite developed its full strength, and in the process of removing the cast facepiece from the mold the silicone ripped. Attempts to remove the entire facepiece from the mold resulted in a number of pieces. The faceseal track was found to be a difficult geometry to demold without damaging the casting. The cast silicone may have done better if allowed to cure for as much as a week to obtain full strength or to accelerate the cure by soaking at an elevated temperature.

Since the objective was to prove the mold, and obtain an artifact to study the geometry of the sculpted facepiece, another silicone material was tried with substantially higher tear strength than the Shin-Etsu KE 106. The opaque white-colored HS II RTV by Dow Corning was used. This was the same silicone used in some of the molding operations described in this report.

With the HS II RTV silicone material, the same steps as for the Shin-Etsu KE 106 optically clear silicone were repeated. After demolding, only a few minor bubbles and voids were observed in the casting. The cast high strength silicone facepiece pulled off of the core with no damage to the faceseal track. The resultant high strength silicone casting is shown in Figure 34. After removing the casting from the mold, since the high strength silicone can bond well to itself, the few minor voids were repaired on the facepiece.

6.6 Epoxy Mold

Following the successful casting of the high strength silicone in the urethane/hydrostone mold, a mold was prepared out of a material that would be capable of casting aliphatic urethane. A review of the recommended processing procedures for the Conap aliphatic urethanes, DPTU-10391 and DPTU-10397, revealed that the preferred cure time was 16 hours at 80 C. For this reason it was desirable to select a mold material that could withstand repeated oven cures without significant degradation. A candidate material was a metal-filled No. 44 High Temperature Epoxy Casting Resin with a S413-C catalyst made by the Fiber Resin Corporation. The metal filled epoxy was used to cast the core and cavity for the casting of aliphatic urethane. The epoxy core is shown in Figures 35 and 36 with the air line inserts.

Since the mold cavity is to be made out of a rigid epoxy instead of the flexible urethane, it was necessary to fabricate the cavity in three pieces, a top and two sides. The 3 parts of the cavity were made by first isolating the sides with a clay wall and casting the top. After the top was cured, the clay walls were removed and the sides were cast by applying a mold release on

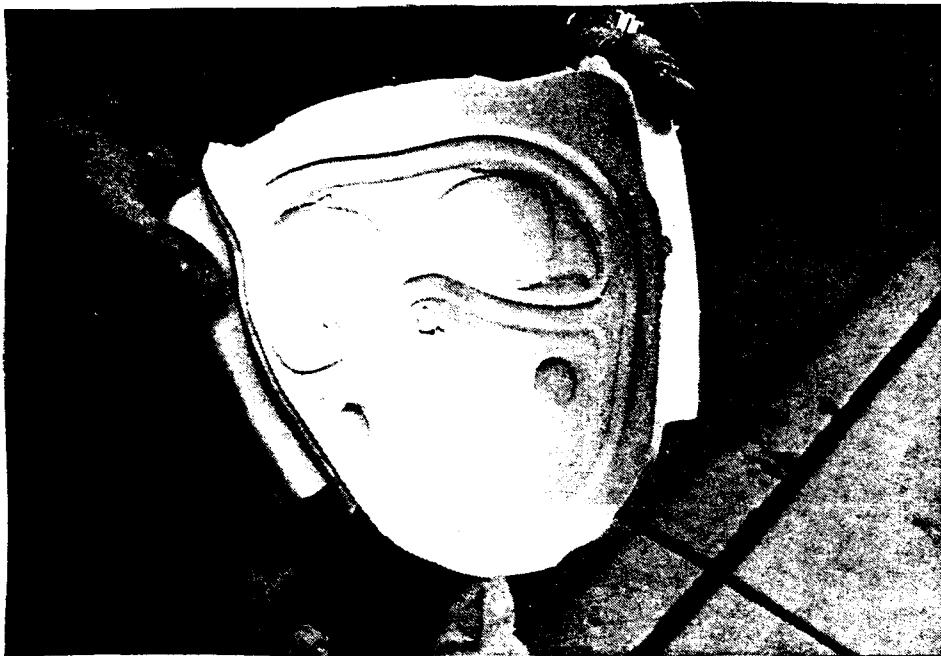


FIGURE 34. HIGH STRENGTH SILICONE FACEPIECE



FIGURE 35. EPOXY CORE

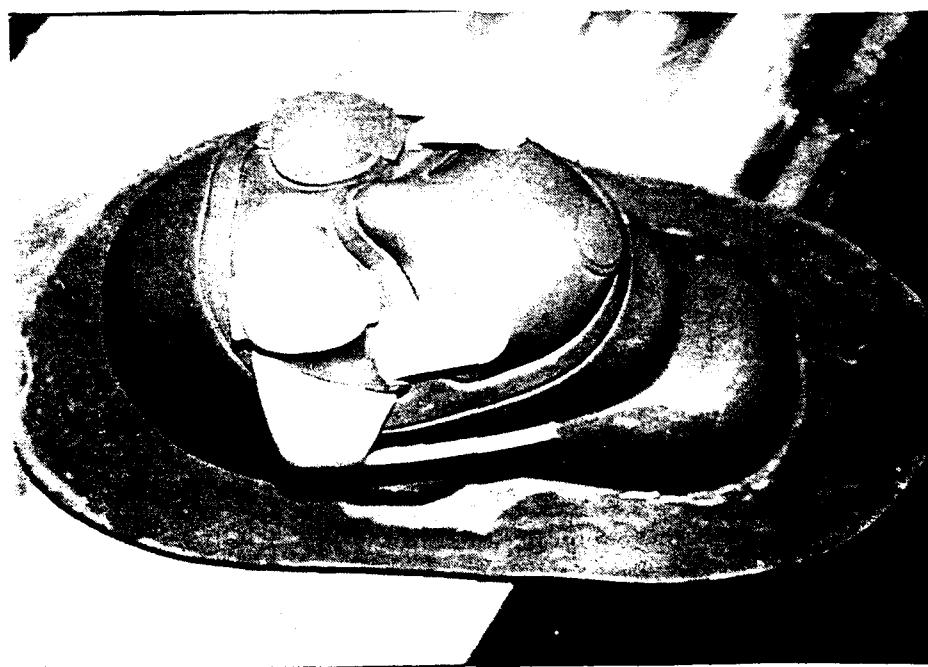


FIGURE 36. EPOXY CORE WITH DENTAL STONE AIR LINE INSERTS

the top. The epoxy material is brushed onto the pattern surface and then applied in layers with pieces of fiberglass mesh for strength.

After the epoxy core and 3-piece cavity were fabricated, these pieces were bolted together and the ports added for filling and venting. The pieces were bolted together to both enhance the strength of the assembled mold and facilitate the alignment of the mold pieces. Figure 37 shows the epoxy core with the air line inserts and the epoxy side pieces of the cavity.

6.7 Casting Facepieces With the Epoxy Mold

There were many variables associated with casting the aliphatic urethane with the epoxy mold. The most critical variables include the mold release, curing procedure, de-molding procedure, vacuum degassing procedure, and pouring/venting procedure. Each one of these variables is a function of the type and brand of elastomer used, the mold material, and the environmental conditions. In order to learn the capability of the material with the mold, facepieces were cast with procedures and methods that worked well for other materials and molds and then modified as the conditions warranted. A facepiece was cast in the epoxy mold using the green opaque material call P.U.R.E. 1040 urethane made by Perma-Flex Mold Company of Columbus, Ohio. The resultant facepiece was demolded with little difficulty, and the quality of the casting was even better than the high strength silicone attempt. There were very few bubbles or void spaces.

After the P.U.R.E. 1040 urethane casting, a casting with the epoxy mold was conducted using the Conap DPTU-10391 aliphatic urethane. The core, cavity pieces, and dental stone air line inserts were prepared with beeswax/toluene release agent. The air line inserts were then positioned onto the core with the use of a tacky all purpose cement. The cavity pieces were carefully assembled and fastened together. After assembly, a bead of silicone sealant was applied along all of the seams between the core and the cavity, and the cavity top and sides. Small reservoirs were carefully positioned around each port. Figure 38 shows the epoxy mold assembly with reservoirs.

The aliphatic urethane parts A and B were mixed together and placed in the vacuum chamber. The degassed pot was poured into the injector, and the aliphatic urethane was injected into the mold, as shown in Figure 39. After waiting 24 hours for the material to cure, an attempt was made to disassemble the mold. However, it was extremely difficult. Several possible reasons were suspected for this failure and included the mold release (did not use the recommend



FIGURE 37. EPOXY CORE WITH DENTAL STONE AIR LINE INSERTS AND EPOXY SIDE PIECES OF CAVITY



FIGURE 38. ASSEMBLED EPOXY MOLD WITH RESERVOIRS



FIGURE 39. INJECTING ALIPHATIC URETHANE INTO EPOXY MOLD ASSEMBLY

material), the ambient conditions (this casting was attempted on a very hot, humid summer day in an environment with no air conditioning), or the insufficient cure time (the product literature recommends a cure of 7 days at 25 °C or 16 hours at 80 °C). Eventually, a cast artifact was removed from the mold, but the quality of the piece was extremely poor. The material ripped easily, it appeared crazed like broken safety glass, and basically the piece never felt like it completely cured, even after 7 days at 25 °C.

As a result of this cast, it was concluded that there are a lot of variables involved with casting aliphatic urethane and that a systematic approach must be established to learning a procedure for each variable.

6.7.1 Iterations on Casting Variables

For each successive casting of the aliphatic urethane, the run was focused on a particular area of concern. In many cases, changing one variable can alter the procedure established for another variable, so castings were iteratively improved with each run.

6.7.1.1 Mold Release

Prior to our first casting with the aliphatic urethane in the epoxy mold, bench top castings were conducted of sample sheets approximately 0.12 inch thick of the aliphatic urethane. These samples were cast onto pieces of glass using various types of mold release. As mentioned earlier, a 20/80 mixture of beeswax/toluene, a 50/50 solution of dishwashing detergent and water, and the manufacturers recommended mold release, Conap MR-5002 were tried. All of the materials appeared to give satisfactory results. Later in the program, the same mold releases were tried on a piece of metal-filled epoxy which showed that a heavy layer of the MR-5002 yielded the cleanest, most trouble free, release.

6.7.1.2 Curing Procedure

The recommended cure was tried next for the Conap DPTU-10391, which was 16 hours at 80 °C. After the aliphatic urethane was cast into the mold, the mold was placed into an oven at 80 °C. The viscosity of the aliphatic urethane decreases slightly during the initial heating. Efforts were made to seal the mold tightly to prevent the cast material from leaking out. After

the initial heating period, the aliphatic urethane starts to set up and thus is less likely to flow out of the mold. After experimenting with the heat cure, the facepiece was found to be demoldable after only about 4 hours at 80 °C. The recommended cure before handling is 2 hours, but with the size and composition of the metal-filled epoxy mold, it takes longer for the aliphatic urethane to reach 80 °C.

6.7.1.3 De-Molding Procedure

After the casting had cured for the recommended period of approximately 4 hours at 80 °C, the mold was carefully disassembled. The general procedure was to scrape off all of the excess silicone sealant from the epoxy mold, then very carefully pry the top and sides until they break free from the urethane casting. After the top and sides of the cavity were removed, the facepiece casting was slowly worked loose from the core. Since the air line inserts were bonded to the core, the inserts were carefully worked loose, breaking the bond. The inserts would remain in the cast facepiece until the facepiece was completely removed from the core. Figure 40 shows a cast aliphatic urethane facepiece with the air line inserts still in place. After working free the bonded air line inserts from the core, the cast facepiece was carefully worked out of the faceseal track. With the facepiece completely free from the core, the air line inserts were wiggled out of the casting. Since the air lines were designed primarily for airflow considerations, the resultant air line insert shapes did not always lend to the casting process. Often times, it was necessary to break the stone air line inserts to remove them from the cast facepiece. The broken air lines were then easily repaired for future castings. Figure 41 shows a cast aliphatic urethane facepiece with the air lines removed.

6.7.1.4 Vacuum Degassing Procedure

In order to insure as bubble and void free casting as possible, a vacuum degassing procedure to the aliphatic urethane was employed. The manufacturers recommendation for vacuum degassing is to degas the pot of the mixed two-part aliphatic urethane to 28-29 inches Hg. This process would work the air out of the urethane prior to casting. Since the aliphatic urethane was injected into the top of the mold full of air, the excess air could possibly be pulled out of the mold after casting. Since reservoirs were added to contain the excess aliphatic

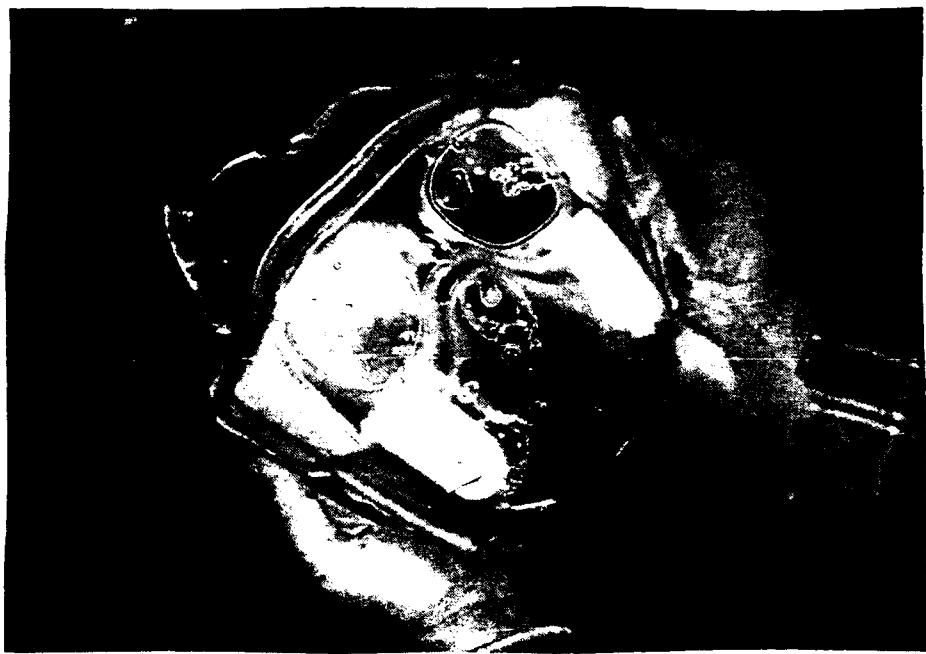


FIGURE 40. ALIPHATIC URETHANE FACEPIECE WITH
AIR LINE INSERTS IN PLACE



FIGURE 41. ALIPHATIC URETHANE FACEPIECE

urethane, during the vacuum degassing of the entire mold the excess material would be held in the reservoirs and would flow into the mold filling the voids formed during the degassing.

Although the material did indeed draw down inside the mold forming voids, the material in the reservoir would not flow into the voids completing the casting. The degassing may have accelerated the cure of the material in the reservoirs, increasing the viscosity, thus preventing it from flowing or since all of the vent holes were covered, this could have prevented the air (in the voids) from escaping, thus inhibiting the material in the voids from flowing into the mold.

Ultimately, the best castings were obtained when the vacuum degassing procedure was used for the pot prior to casting. The best way to remove air from the mold appeared to be by routing the flow of material to force out the air as the material is injected into the mold. Limited success was obtained by tilting the mold during the injection process, which filled the mold from the neck area to the top of the head allowing air inside the mold to escape via the ports at the corners of the lenses.

6.7.1.5 Pouring/Venting Procedure

As discussed in the section on vacuum degassing, the best configuration for casting was to allow the material to enter at the geometric low point in the mold and slowly fill the mold forcing the entrapped air out of vents located at the high point of the mold. After studying the mold it was determined that the best way to fill it would be to invert the mold, nose facing down, and fill the mold through the tip of the nose (the low point) and allow the mold to fill pushing the air out of the rim of the facepiece (the high point). This procedure was attempted and good results were obtained. The casting made with the bottom pour method was virtually void and bubble free. The only place where air was trapped (thus causing an incomplete casting) was along the inside rim of the faceseal track. Small vent holes could remedy this minor problem.

6.8 Alternative Casting Material

Throughout the course of the program, different materials and different manufacturers of the same materials were identified for use on the demonstrator model multi-layer mask. Most notably, another aliphatic urethane supplier was identified. Since, at the time, difficulties were experienced casting the Conap DPTU-10391 and DPTU-10397, other aliphatic urethanes from competitive material suppliers that possibly worked better were found. Samples were obtained

of an aliphatic urethane referred to as TC-512 made by BJB Enterprises, Incorporated, in Garden Grove, California. In addition, a spray mold release called Epoxy Par-Film that was recommended by representatives of BJB Enterprises for our particular application was also obtained.

After trying the BJB material on a sample facepiece casting, the TC-512 appeared to produce clearer castings than the Conap materials. The TC-512 also cured more completely over the same time, and when using the TC-512 with the Epoxy Par-Film mold release, the castings demolded easier and inserts could be removed easier. A range of hardnesses (50 to 65 Shore A) could be obtained by manipulating the ratio of the two-parts for the TC-512. Later in the program this became an important option since the cast facepieces were determined to be too stiff at 65 Shore A.

The disadvantage with the TC-512 was that, even though the material is sold as a clear, non-ambering urethane elastomer, after a casting has set in a partially sun-lit environment for approximately one month, it develops a very slight amber tint. The Conap materials remained clear when subjected to the same conditions. BJB Enterprises was investigating the additives to determine if perhaps a cold weather curing additive was causing the ambering. BJB Enterprises also suggested that the ambering could be compensated for during the casting process by adding a very slight amount of blue tint to the two-part mixture. This was considered to be a minor problem and could be resolved with further investigation. If a completely, non-ambering, water clear mask was desired, it could be cast using Conap material.

6.9 Sew Hood/Suspension

With cast facepieces and a detailed design of the multi-layer mask hood and suspension, these items could be fabricated. Early in the program, an industrial sewing contractor, Super Stitches of Columbus, Ohio, was contacted and contracted to fabricate some preliminary prototypes of the basic hood design. This effort resulted in two hoods that were sewn together with urethane coated nylon pack cloth. These early hoods provided a valuable mechanism to understand fit, comfort, bulk, and overall appearance. With these basic hoods, a suspension supplied by CRDEC, and a representative facepiece, Costume Specialists, of Columbus, Ohio, was contracted to fabricate an integrated ensemble. The suspension was designed with a zipper to facilitate removal for anticipated redesign after evaluation. Some assumptions were made

with regard to air passageway routing and the filtration system, but a demonstrator hood with an associated suspension was fabricated and attached to a cast facepiece.

6.10 Establish Filter Design

Initially, the filter design was envisioned to be a two element design, located on the bib of the multi-layer hood, and with an effective surface area of 40 to 50 sq in. For this design, two 4 by 6 inch filters were selected which combined for a total filter area of approximately 48 sq in. A material thickness for the filter element of approximately one-half inch was selected based on filter samples obtained early in the program. These mock filter elements were added to the early multi-layer mask demonstrator model for appearance only. The filter elements were not intended to provide any kind of filtration protection.

6.10.1 Discussions With Aerosol Group

The effort to evaluate filtration materials for use in the multi-layer mask was conducted by the aerosol group at Battelle on a task for CRDEC titled "Evaluation and Optimization of a Flexible Filtration System for Respiratory Protection System 21". The aerosol group conducted tests evaluating potential filtration materials with regard to airflow resistance, aerosol filtration efficiency, gas life, required surface area, and flexibility. Throughout the program, information exchange was maintained with members of the Battelle aerosol group so that constant update of the design could occur as more filtration evaluation results became available.

6.11 Multi-Layer Mask Integration

With a cast facepiece, hood, suspension, and filter-mock-up, the first preliminary mock-up demonstrator model of the multi-layer mask concept was assembled. Although examples of transparent facepieces made from aliphatic urethane were available, these early castings contained voids and air bubbles which detracted from the appearance of the assembled model. Also, since the early aliphatic urethane facepieces were quite stiff, it was very difficult to sew a transparent facepiece to the hood and suspension. The opaque white high strength silicone mask was virtually void free after repairing some minor flaws, and it was compliant enough to be sewn to the hood and the suspension. Thus, the first multi-layer mask model was assembled with an

opaque white facepiece. Even though the mask wearer could not see out of the mask, it was still possible to obtain valuable information regarding fit, comfort, flexibility, and overall appearance. Figure 42 shows the first multi-layer mask model with the high strength silicon facepiece.

7.0 TEST

7.1 Airflow Resistance

Since the aerosol group was testing potential filtration materials for airflow resistance at various airflows, the same test equipment and procedures were applied to the facepiece. A transparent aliphatic urethane facepiece with a high strength silicone solid faceseal was supplied to the aerosol group for airflow resistance testing and evaluation. The aerosol group mounted the facepiece to a small size test headform. Figure 43 shows the facepiece test set-up. Since the facepiece was made from a relatively stiff aliphatic urethane, a solid elastomeric faceseal was used, and the headform and the facepiece were not specifically sized for one another, there were some gaps that needed to be caulked prior to testing. Due to the format of the airflow resistance requirements for the multi-layer mask, it was of primary interest to determine the airflow resistance through the facepiece at a flow of 85 lpm. A graph describing the airflow resistance for a range of flows is shown in Figure 44.

7.2 Optics

The optical clarity of the cast facepieces was dependent on surface finish of the mold. A polished surface resulted in a clearer casting than a rougher surface. Aliphatic urethane cast on glass resulted in excellent clarity. In order to assess the optical properties of a lens or lens system, it was necessary to accurately control not only the surface finish of the lens but also the accuracy of the distance between the two lens surfaces. Since the facepieces were cast in hand layed-up molds it was almost a certainty that the distance from front to back of the lens was not accurately maintained. Even with a polished mold surface, the thickness discrepancy would contribute to optical distortion. Other fundamental problems needed to be resolved before dedicating valuable casting time to improving the surface finish of the mold. However, the surface finish of the mold could be improved when all of the variables associated with the casting process had been sorted out.



FIGURE 42. HIGH STRENGTH SILICONE FACEPIECE
ATTACHED TO AN EARLY HOOD MOCK-UP



FIGURE 43. ALIPHATIC URETHANE FACEPIECE ON TEST SET-UP FOR AIR FLOW RESISTANCE

Airflow Resistance Tests of Facepiece

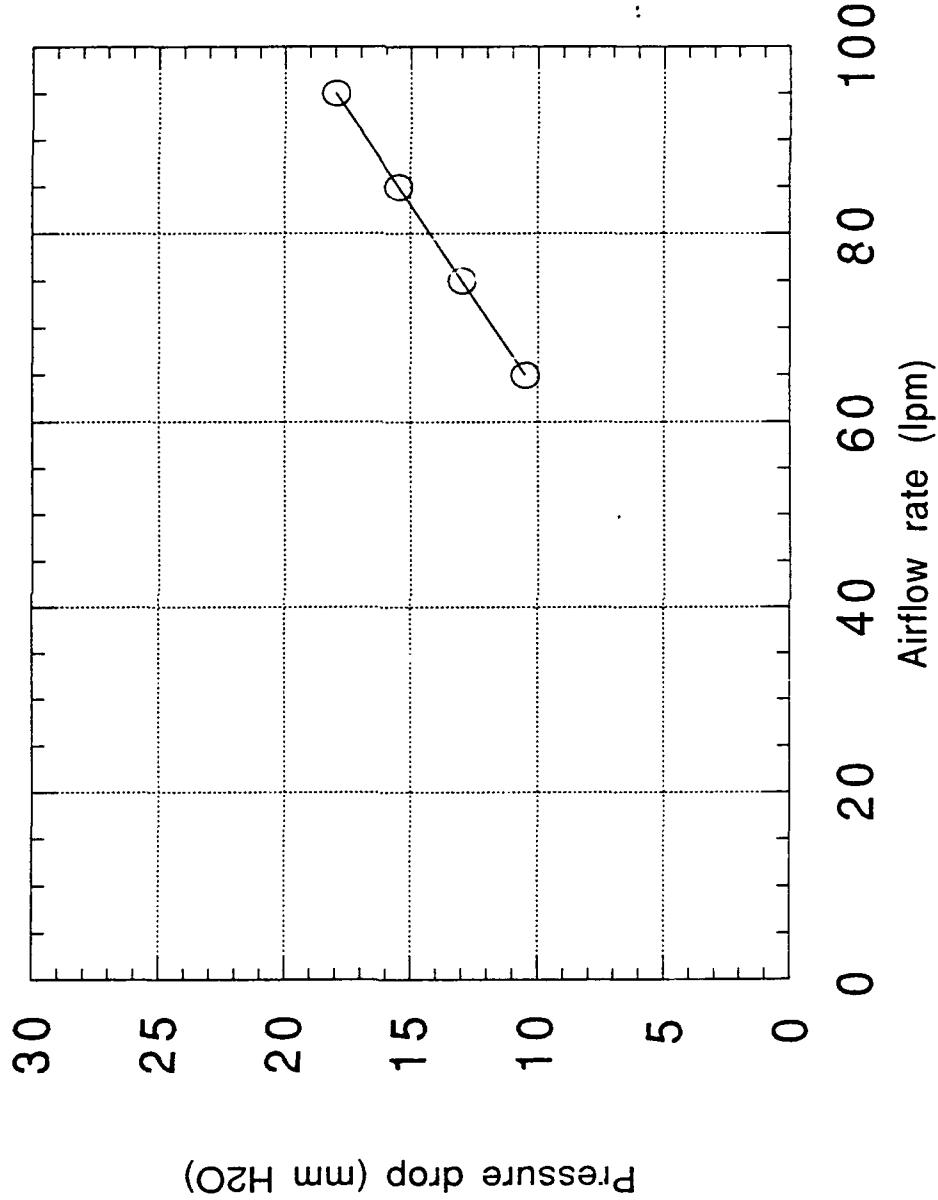


FIGURE 44. AIRFLOW TEST RESULTS OF ALIPHATIC URETHANE FACEPIECE

7.3 Fit

Since fit over a range of sizes was not an issue for this program, the issue of fit can only be addressed to the headform from which it was made. In order to test the fit fairly, a mask leakage test needs to be conducted with a head testform built from the headform used for the mask design and fabrication. It is possible that a 50 percentile male test head with measurements within a given range of tolerance should provide an adequate basis to perform leakage tests with the cast facepieces from this program. In addition, the fit and thus the leakage of the demonstrator model multi-layer mask is a function of the faceseal. Since the anticipated gel-filled faceseal is still under development, it is difficult to evaluate the quality of fit at this time.

7.4 Comfort

The comfort of the multi-layer mask model is in some ways a subjective evaluation. However, there can be some generalizations made about the mask comfort. How tight the mask needs to be secured to the users head is essentially a function of the faceseal. An effective, conforming faceseal will require minimal force to retain on the head and thus will greatly influence the perceived comfort of the multi-layer mask.

7.5 Interference with Existing Equipment

It is difficult to determine the extent to which the demonstrator model of the multi-layer mask interferes with other existing equipment. Tests were conducted while wearing the mask and aiming an M16 rifle, but without effective data measurement. During design optimization of the multi-layer mask it would be imperative to better coordinate the consideration of existing equipment for the personnel for which the mask was intended.

7.6 Appearance

The appearance of the multi-layer mask demonstrator model was quite different from that which was anticipated by the client. The multi-layer mask shown in the patent disclosure, included in the appendix of this report, shows a much slicker, more compact design.

All of the components have been modeled by building the mask from the face up with function in mind. Many of the requirements established at the beginning of the program have dictated the size and shape of the features shown on the demonstrator model. The components can be stylized, to a certain extent, into a more attractive, aesthetically pleasing design, but this requires time and money to implement. Also, the function needs to be maintained in order to insure that the mask will perform competitively when compared to existing mask designs.

8.0 EVALUATE

8.1 Demonstrations

During the early stages of casting facepieces, an artifact was furnished to CRDEC from the casting trials. The best casting at the time was with the P.U.R.E. 1040 urethane material. Although the material was opaque, the cast facepiece provided a three dimensional artifact of the mask design and indicated the potential quality with the sculpted molds. After review by CRDEC, a list of comments on the facepiece design was prepared. The list is included below:

1. Any additional weight should be removed by reducing wall thicknesses and/or reconfiguring the design.
2. The ducting in the front may interfere with rifle firing and should be checked with a rifle before moving to the next stage.
3. The ducting on the side may interfere with the helmet system, especially the combat vehicle helmet with earcups and should be checked before moving to the next stage. We are going to be looking at moving all ducts inside the seal in our design. This may prove beneficial and should at least be considered in your design.
4. We envisioned the lens system to be a windshield type design so that binocular field-of-view can be optimized. This needs to be revised on the outer surface.
5. The lens size and shape should be checked to assure a high level of field-of-view especially in the down direction.
6. Features may have to be incorporated to allow for the addition of a suspension, hood, facepiece cover, etc. These should be thought through before moving to the next stage.
7. It is impossible to tell anything about the seal at this time.

8. Airflow resistance should be checked to assure the pressure drop is within the established range.
9. We envision producibility problems with the current design, especially with the ducting. Other approaches such as our sandwich layer design should be considered.

All of these comments were taken into consideration for the redesign of the facepiece.

8.2 Identify Changes/Modifications

After consideration of the test results as well as the observations and feedback from the client, changes and modifications were identified for the final iteration of the multi-layer mask demonstrator model for this program. Major areas of concern included an improved faceseal, improved facepiece profile, improved optics, lower durometer facepiece, improved overall quality of demonstrator, and increased filtration area.

8.2.1 Face seal

At the time of the initial demonstrator model testing and evaluation, the only faceseals available were cast from a solid elastomeric material. The materials used were either P.U.R.E. 1040 urethane with a hardness of approximately 60 Shore A or a high strength silicone with a hardness of around 30 Shore A. These solid elastomeric faceseals provided a means to allow the mask to contact the face, but these seals were not as soft and conforming as the anticipated gel-filled faceseal.

The primary design of the gel-filled faceseal was to bond together two pieces of vacuum thermoformed materials that made up the outside geometry of the faceseal. The bonded together thermoforms formed a hollow shell of the faceseal into which the silicone dielectric gel would be injected. After the gel was cured, the faceseal assembly could be trimmed and fitted into the facepiece for evaluation.

Due to the complex geometry of the designed and sculpted faceseal, it was extremely difficult to find an appropriate method to bond the two vacuum thermoformed sheets together. Heat sealing, radio-frequency heat sealing, ultrasonics welding, and adhesives were investigated as potential methods. The most feasible methods were found to be heat sealing and radio-frequency heat sealing. Both of these approaches required special tooling to support the vacuum thermoformed sheets during the sealing process. Upon communicating the need for tooling to

the client, the reaction was to investigate methods that are more flexible and less tooling dependent to accommodate the anticipated design changes.

Several manufacturers and distributors of equipment for heat sealing without tooling were contacted. This equipment includes hot-air and hot-wedge sealing machines that operate much like a sewing machine. In addition, representatives from the Battelle project team attended the Industrial Fabrics Association International 1991 Industrial Fabric and Equipment Exposition in Nashville, Tennessee. At this show, demonstrations of potential sealing equipment were observed for our specific needs. None of the non-tooling oriented sealing equipment observed at the exposition could satisfactorily bond together the vacuum thermoformed materials in the geometry of our design.

At the Industrial Fabric and Equipment Exposition, contact was made with several manufacturers of machinery that performs radio-frequency heat sealing. After discussing the requirements with several of the vendors it became apparent that relatively inexpensive tooling could be cast to accommodate the unusual geometry of the faceseal, and the resultant tooling could be used to make high quality bonds of the thermoformed sheets. Due to time and money limitations, this work was not done on this program.

8.2.2 Facepiece

The problem areas identified for the facepiece include the need to improve the position and shape of the air lines, reduce the hardness of the overall material, use a windshield for the intermediate lens instead of the individual lenses, and improve the optical clarity.

The air lines need to be more form fitting to the shape and contours of the headform. This will result in a much more efficient profile in terms of airflow resistance, thinner wall thicknesses, and overall lower profile. With a slicker air line shape, this will also enable the air line inserts to be pulled out of the cast facepiece easier.

The stiffness of the cast facepieces can be improved by adjusting the ratio of the two-part aliphatic urethane. For the BJB Enterprises TC-512 material, the range of hardness goes from 50 to 65 Shore A. More flexible ratios can be cast but the manufacturer will have to be consulted to determine what other factors will be effected.

In order to obtain a facepiece with greater clarity, particularly through the lens area, it is necessary to polish the mold surfaces. With the materials currently in use for the facepiece casting, a more polished surface should result in better clarity. As stated earlier in this report,

since the molds were hand sculpted, the wall thickness of the aliphatic urethane lens may vary. This difference in wall thickness may result in some visual distortion.

8.2.3 Filtration System

The results of the filtration study identified two potential filtration medias for further design considerations. Requiring the surface area of the filter elements to be between 40 to 50 sq in. implied that with one of the candidate filtration medias, the filter element thickness was approximately 1 inch, and with the other candidate filtration media the airflow resistance was quite high when compared to the anticipated performance. In order to reduce the filter element thickness for the one media, or decrease the airflow resistance for the other media, it became necessary to increase the surface area of the filter element.

After discussion with the client, it was decided to increase the filtration surface area from the range of 40 to 50 sq in. to 100 sq in. This increase in filtration surface area had an effect on the initial design of the multi-layer mask model. The major concerns of the change to the 100 sq in. filtration surface area are listed below:

- The proposed 100 sq in. filter uses most of the area of the chest leaving little room for the electronics.
- Adding the blower will potentially require a re-evaluation of the filter requirements, possibly increasing the area and/or thickness of the filtration media. If all of the chest area is used (for the 100 sq in. filter), little room is left for expansion.
- If a molded frame is required to encapsulate the filtration media, the resultant filter cartridge may be relatively stiff. It may be better to have two smaller stiff filter cartridges that can move independently than one large stiff cartridge that may restrict movement.
- Logistically, the two filter approach may provide an option to change filter cartridges in the field while still wearing the protective mask, whereas the one filter cartridge approach may require replacement in a "clean" environment.
- It is possible that the one filter cartridge (100 sq in.) could be mocked up with the lightweight protective mask that was not intended to utilize any electronic components.

These concerns were communicated to the client along with six concepts for the filter elements layouts. The six concepts are shown in Figure 45. After review of the major concerns

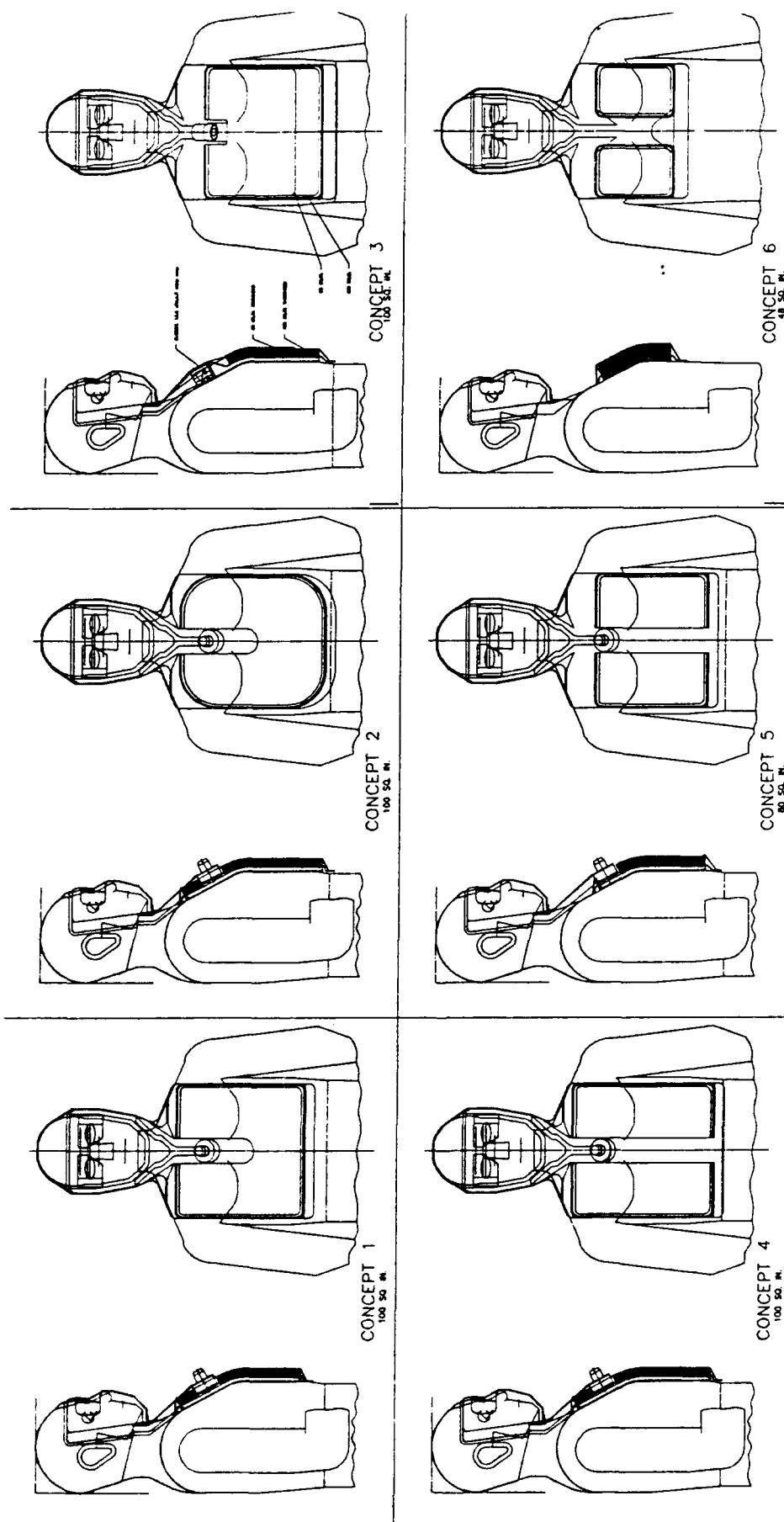


FIGURE 45. SIX CONCEPTS FOR FILTER ELEMENT LAYOUTS

and layouts for filter elements, the client selected the single 100 sq in. filter element as the candidate approach. With this decision in mind, changes were made in the hood design to accommodate such a filter element.

8.2.4 Filter Element Tooling

In order to fabricate an elastomeric frame to encapsulate the stack of filtration and spacer material it was necessary to design an insert mold. The idea behind the insert mold is to place the stack of filtration material and spacer material into a mold that provides a cavity around the outside edge. This cavity is then filled with an elastomeric material that hardens and seals the stack of filtration materials together. A design for the insert mold tooling for the 100 sq in. size filter element was prepared. Unfortunately, due to time and cost constraints, the insert mold for the filter element assembly was not fabricated.

9.0 MODIFY

Modifications and changes were implemented for the second iteration of the demonstrator model multi-layer mask. Changes and modifications to the facepiece were performed during the subsequent mold sculpting procedure. Changes and modifications to the hood were implemented to accommodate the 100 sq in. filter design. The 100 sq in. filter was designed in close association with the aerosol group at Battelle. This group needed to be able to test and evaluate the design for a 100 sq in. filter element, while the needs of this program were to have a representative working filter element for our demonstrator model. The aerosol group made 100 sq in. filter elements with the two recommended choices of filtration media. These filter elements consisted of stacks of the designated filter media and spacer material that were sealed and bonded around the edges with siliconized latex caulk. A transition tube, fabricated from a modified sweeper attachment, was positioned and caulked onto the stack of filter element material. Figure 46 shows the 100 square inch filter fabricated for testing and evaluation.

9.1 Improve Casting Technique/Procedure

During the casting process of the facepiece for the multi-layer mask, the best, most bubble and void free results were obtained when the casting was bottom poured. The bottom

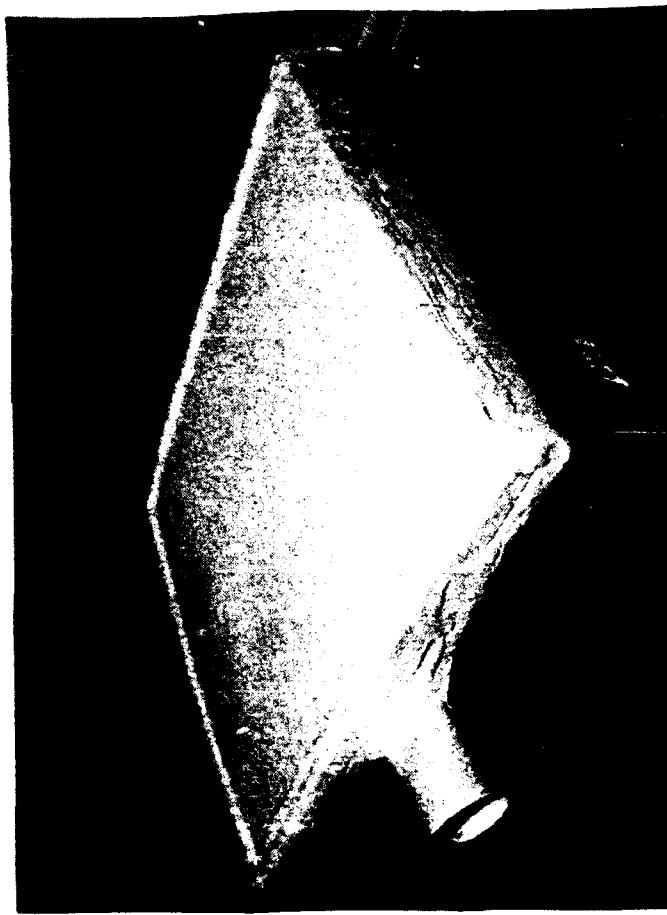


FIGURE 46. SCALE MOCK-UP OF 100 SQUARE INCH SURFACE AREA FILTER ELEMENT

pouring technique implies filling the mold from the bottom and allowing the cast material to force the entrapped air out of the mold through vents positioned at the top of the mold. With this in mind, the new facepiece mold was designed to be filled from the bottom and included air vents near the top.

9.2 Reshape Facepiece

In order to accommodate the desired geometry changes to the multi-layer mask, it was necessary to re-sculpt the core, cavity and the air line inserts. Since the geometry and composition of the faceseal could not be evaluated, the faceseal and the faceseal track was retained on the facepiece. Because all of the headforms were retained as the initial facepiece mold development progressed, the new facepiece design was started by sculpting the new geometry onto the headform with the faceseal and faceseal track intact.

9.2.1 Sculpt New Model

Using the same procedure as before, the headform was clayed up with the faceseal to resemble the improved, lower profile design. In order to accommodate the more efficient air line shapes, it was necessary to select an optical correction lens shape that allowed for more clearance along the nose line. The new lens shape is shown in Figure 47. With the new lens shape, a pair of frames were selected and modified to accommodate the multi-layer mask corrective lens design. The unmodified frame with corrective lenses is shown in Figure 48.

After positioning the lenses, the inside geometry of the modified facepiece was filled with clay. Check valves were used from existing mask designs to enhance the quality and function of the demonstrator model. The selected check valves were used to make aluminum blanks for casting purposes.

The air lines were sculpted to represent a more flowing, streamlined shape. A CAD drawing of the modified air lines provided guidance for the sculpting effort. Figure 49 shows a representation of the facepiece with the improved air lines. Since the facepiece was to be cast with the mold positioned upside down in order to accommodate the bottom fill approach, it was necessary to secure the air line cores with fasteners to the facepiece core. This was accomplished by match drilling the inserts when placed onto the mold, then tapping the inserts to accept a machine screw that would be attached from the inside, hollowed out portion, of the core.

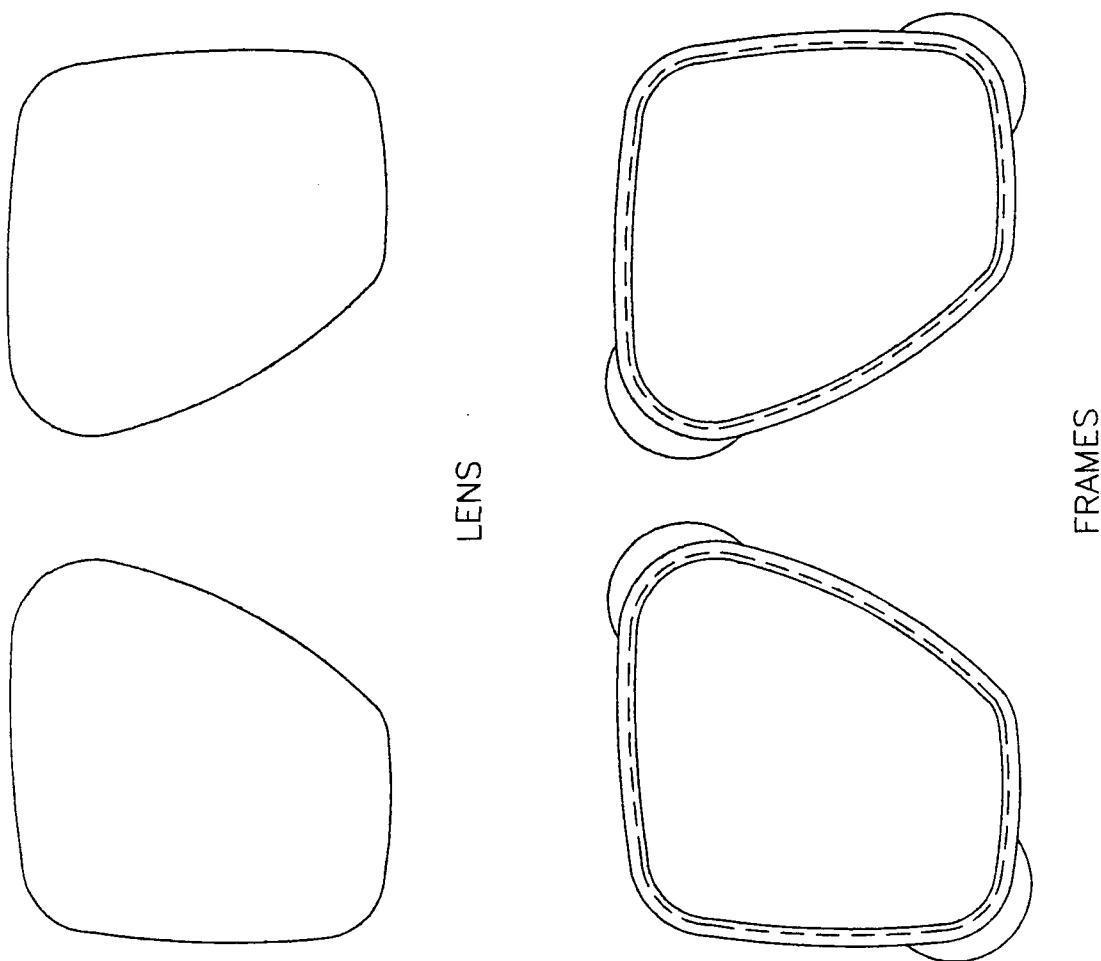


FIGURE 47. NEW LENS SHAPE WITH RESULTANT FRAMES



FIGURE 48. LENS AND FRAME OF FINAL DESIGN
INTEGRATION CORRECTIVE LENS
INSERT PRIOR TO MODIFICATION

9.2.2 Generate Molds

Similar to the technique described for the first molds, the new molds were cast out of metal filled epoxy. The core was modified to accommodate the air line inserts, while the cavity was made in three parts to facilitate mold assembly. Figure 50 shows the newly designed core with air lines in place.

9.2.3 Cast Facepieces

As before, the new facepieces were cast with the main difference being how the material was injected into the mold forcing the entrapped air out. The new mold was designed to be filled with the mold positioned nose down. A port added to the nose area permits the aliphatic urethane material to be injected at the low point of the casting and fill the mold forcing air out of the periphery of the facepiece, or high point, of the casting.

10.0 RESULTS

The results of this effort were that a demonstrator model of the multi-layer mask was researched, designed, developed, and fabricated. A description of the final model is given below.

10.1 Final Description

The demonstrator model of the multi-layer mask fabricated during the course of this program consists of the following components: a transparent elastomeric facepiece, solid elastomeric replaceable faceseal, a replaceable elastic suspension, a representative hood, and a filtration element. Later additions may include electronics consisting of a blower, a communication system, and a power supply. The communication system will include a microphone, a speaker and an amplifier. The final design is shown in Figure 51.



FIGURE 50. CORE WITH CLAY AIR LINE INSERTS
OF FINAL DESIGN ITERATION

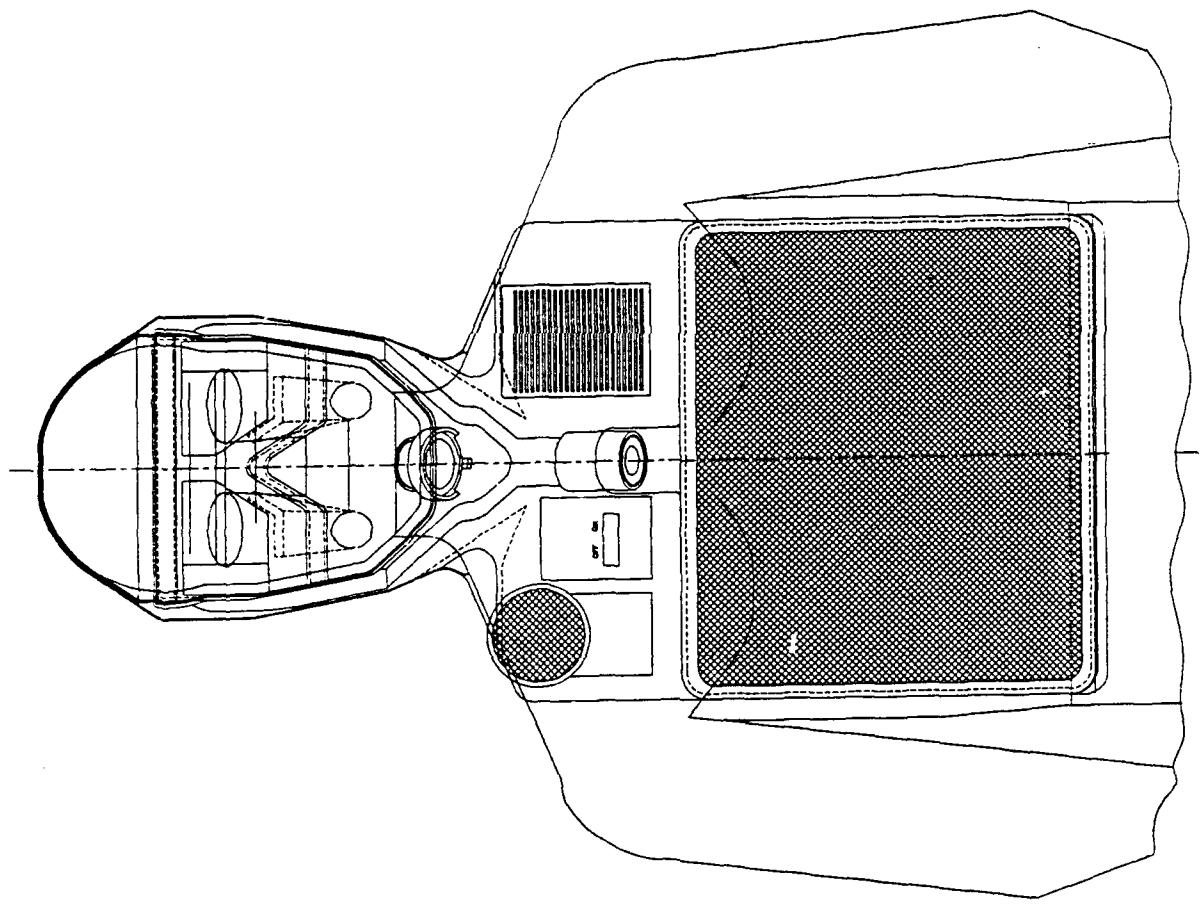
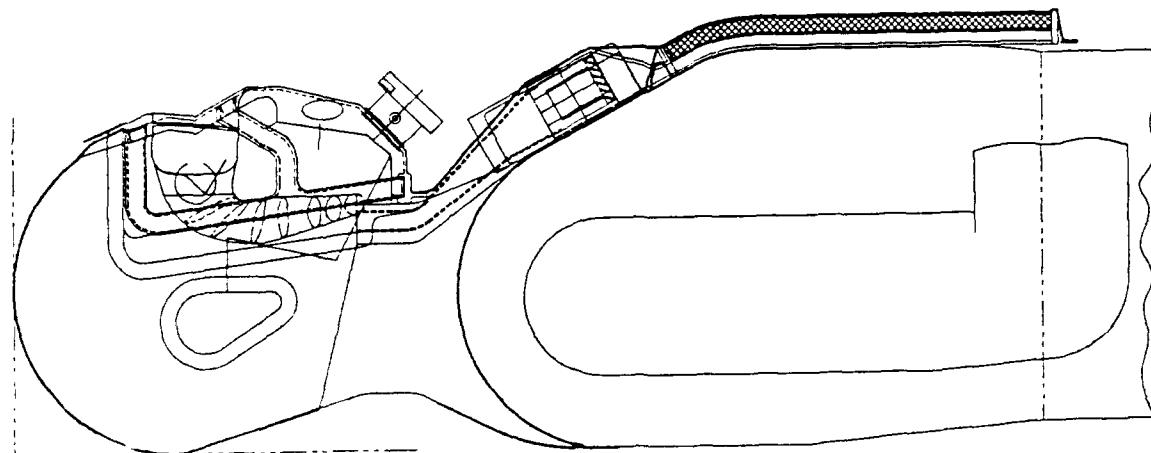


FIGURE 51. FINAL DESIGN OF THE MULTI-LAYER
MASK DEMONSTRATOR MODEL



**THIS
PAGE
IS
MISSING
IN
ORIGINAL
DOCUMENT**

12.0 RECOMMENDATIONS

The work done on this program was split between identifying and understanding all of the requirements and specifications available for the multi-layer mask design, reviewing and investigating materials appropriate for the final multi-layer mask configuration, and developing the technique and procedure to turn the multi-layer mask requirements and specifications into representative models for evaluation.

The majority of the program was directed toward developing the ability to turn design characteristics into tangible artifacts for testing and evaluation. For example, while it took nearly 7 months to produce a casting of a facepiece that was representative of the initial design, the redesigned facepiece took approximately 1-1/2 months to design and fabricate a facepiece of comparable quality. This is a significant reduction in the learning curve of mask model making.

With the above stated increase in ability to respond to design changes with a 3-dimensional shape, it is recommended that the work of the multi-layer mask continue with the refinement and modification of similar models. It is also recommended that as the models develop, since it is likely that at some point it will be of interest to manufacture the multi-layer mask, that an effort be conducted that will investigate the manufacturing options for the multi-layer mask with the anticipated materials and design.

It is recommended that the work conducted to sort out all of the multi-layer mask design characteristics, and the experience gained from the facepiece, hood, suspension, filtration, and electronics model building, be used to improve the quality and function of future efforts.

APPENDIX A

DRAFT RESPO 21 DEVELOPER'S SPECIFICATION

M40 MASK REQUIREMENTS

1.1.1.1. Lire - 300,000 mg-min/m³, minimum,
0,000 mg-min/m³, design goal)

2 Agent: Soman (GD)
Concen: 700 + 50 mg/m³
Flow: 32.0 + 1.0 lpm, cont
Temp: 75 + 5°F
Rel Hum: 50 + 5 percent
End Point: 0-04 mg/m³
Pre-equilibration: None

1.1.1.3 CK Life - 40,000 mg-min/m³, minimum
(120,000 mg-min/m³, design goal)

1.1.1.3 Agent: Cyanogen Chloride (CK)
Concen: 4,000 + 200 mg/m³
Flow: 32 + 1.0 lpm, simulated breather flow
33 + 2 cycles/min
Temp: 75 + 5°F
Rel Hum: 80 + 3 percent
End Point: 8 mg/m³
Pre-equilibration: 80 percent rel hum @ 80 +
10°F

1.1.1.4 Other chemical agents - equal to or greater
than M13A2 Filter Elements of the M17A1 Mask based
on comparative agent tests under equivalent
conditions.

1.1.1.4 Other chemical agents.

1.1.1.4.1 Agent: Hydrocyanic Acid (AC)
Concen: 10,000 + 500 mg/m³
Flow: 32 + 1 lpm constant
Temp: 75 + 5°F
Rel Hum: 50 + 5 percent
End-Point: 8 mg/m³
Pre-equilibration: None

1.1.1.4.2 Agent: Phosgene (CG)
Concen: 20,000 + 500 mg/m³
Flow: 32 + 1 lpm, constant
Temp: 75 + 5°F
Rel Hum: 50 + 5%
End-Point: 8 mg/m³
Pre-equilibration: None

EVALUATION CRITICAL AND WORST CASE CONDITIONS

EVALUATION CONDITIONS AND WORST CASE CONDITIONS

- 1.1. 3 Agent: Arsine (SA)
Concen: $10,000 \pm 500 \text{ mg/m}^3$
Flow: $32 \pm 1.0 \text{ lpm}$ breather
Temp: $75 \pm 5^\circ\text{F}$
Rel Hum: $80 \pm 3 \text{ percent}$
End Point: 10 mg cumulative
pre-equilibration: 80 percent @ $80 \pm 10^\circ\text{F}$
- 1.1.1.4.4 Miscellaneous agents - Data on miscellaneous chemical agents shall be collected for information purposes as required or requested by TRADOC or other interested agencies.
2. Atmosol protection (canister):
- 2.1 Chemical: 0.01 percent penetration, maximum
- 2.2 Radiological: 0.01 percent penetration,
 $\lambda_{\text{rad}} = 0.0001$
- 2.2 Biological: 0.0001 percent penetration,
 $\lambda_{\text{biol}} = 0.0001$
- 1.2.1 & 1.2.2 Penetration shall be measured using a thermally-generated DOP aerosol of uniform 0.3 micron diameter particle size at a continuous flowrate of 32 lpm. Evaluation shall be made using a Q127 aerosol penetrometer or equivalent apparatus.
- 1.2.3 Penetration shall be measured using a biological aerosol of *B. globigii* spores having a minimum concentration of 1×10^5 organisms/liter with a particle size of 1 to 5 microns diameter and at a simulated breather flowrate of 32 lpm. Tests shall be conducted in accordance with the procedures outlined in Protection Branch Report of Test No 2-68, Evaluation of Three Types of Experimental Filter Elements, Physical Defense Division, Fort Detrick, MD, 2 Nov 67.

OVERALL MASK LEAKAGE WITH AND WITHOUT
CANISTERS/INSERTS WITH AND WITHOUT PROTECTIVE
MASKS

SITUATION CRITERIA AND VALUES

3.1 d) 3.2 Aerosol tests - Penetration will be measured on all sizes of masks properly fitted to lean shaven human test subjects wearing appropriate headgear (1). Tests will be conducted under moderate activity conditions and will include:

Running in place
Rifle sighting
Optical coupling

(1) PASGT (to include airborne configuration) and M1 helmet (to include airborne configuration), SPH-A helmet, DH132 helmet, and OH140 helmet.

3.1 Biological aerosol - Maximum of 0.002 concentration

Chemical and Radiological Aerosol - Maximum 2.75 percent penetration

EVALUATION CONDITIONS AND PROCEDURES

1.3.1 and 1.3.2 Normal breathing
Rapid breathing
Facial distortions
Rapid head movement - horizontal and vertical

1.3.2 NaCl Leakage Test or suitable substitute:

Concen: 15 mg/m³
Particle size: 0.7-0.8 micron mean mass diameter
Detection: Flame photometric
Sensitivity: 0.001 percent penetration

1.3.2.2 Corn oil

Concentration: 25 mg/m³
Particle size: 0.5 micron Mass Median
Acrodynamic Diameter
Detection: Forward Light Scattering
Sensitivity: 0.01 percent of challenge concentration

4. PERIODIC TEST OF MASK COMPONENTS TO CHEMICAL
THERSES:

4.1 Liquid Agent Exposure/Vapor Permeation:

Mustard (HD): 360 minutes, minimum
Thickened Soman (TGD): 360 minutes, minimum
V-agent (VX): 360 minutes, minimum

1.4.1 Samples from the faceblank with hood combination and lens shall be tested per EP-TR-76061 and MIL-STD-282, Methods T-208 and T-209 using the following parameters:

- (1) cup size: 37-mm I.D. (10.75 cm² test area).

(2) exposed area open to the atmosphere, and

(3) agent drop size: one 6-ul drop.

(4) The vapor permeation end-point shall be determined at the earliest occurrence of the following criteria:

- (a) Effluent Ct exceeds 50 mg-min/m³ for HD and 15 mg-min/m³ for TGD and VX, or
- (b) Effluent concentration exceeds 2.0 mg/m³, or
- (c) Total test duration exceeds 450 minutes or is run until failure occurs per (1) or (2) above.

Vapor Agent Exposure:

Cyanic Acid (HCN): 360 minutes, minimum

1.4.2 Samples from faceblanks (or silicone slabs of comparable thickness) shall be mounted in a suitable test fixture and exposed to a continuous concentration of 4 mg/l of HCN at 50 percent relative humidity. A flow of clean air shall be maintained across the effluent surface of the sample equivalent to 4 lpm per 100 cm² area of sample. The vapor permeation end-point shall be determined at the earliest occurrence of the following criteria:

- (1) Effluent Ct exceeds 50 mg-min/m³, or
- (2) Effluent concentration exceeds 11 mg/m³, or
- (3) Total test duration exceeds 450 minutes or is run until failure occurs per (1) or (2) above.

The canister shall be NATO interchangeable and quickly and easily replaceable, while wearing CB/environmental suit(s), yet without removing the mask from the face by an individual. The mask will provide for mounting on either the left or right side of the facepiece.

EVALUATION CRITERIA AND VALUES

REPLACEMENT TIME

- 2.1 The replacement time will be the time it takes a subject to remove the canister from the mask and replace with another canister. The replacement filter will be unpackaged. The replacement operation will be done with and without both CB and environmental handwear excluding the Arctic mittens. The operational temperatures will range between -25°F +120°F.

REMOVAL OR REPLACEMENT

No special tools, materials, or special equipment required for canister replacement; canister may be mounted on either side of the facepiece.

INJECTION

Protection shall not be degraded to the filter.

CHARACTERISTIC - SPEECH/COMMUNICATION:

The mask shall permit intelligible voice transmission (face to face) and shall not interfere with hearing. It shall permit the use of receiving and transmitting communication devices currently in use by the services, those in development, and those in use at the time of new mask availability.

EVALUATION CRITERIA AND VALUES

The average modified rhyme test (MRT) score shall be less than 75 percent.

EVALUATION CONDITIONS AND PROCEDURES

- 2.1 The replacement time will be the time it takes a subject to remove the canister from the mask and replace with another canister. The replacement filter will be unpackaged. The replacement operation will be done with and without both CB and environmental handwear excluding the Arctic mittens. The operational temperatures will range between -25°F +120°F.

Self-explanatory.

- 2.3 The mask shall be tested for aerosol leakage with an M14 Mask Leakage Tester per Product Assurance Instruction Manual 136-300-18B or equivalent apparatus.

EVALUATION CONDITIONS AND PROCEDURES

- 3.1 The modified rhyme test (MRT) per Human Engineering Guide to Equipment Design shall be used (MIL-STO-1472C, para 5.3.12.1.b) over a range of human subjects (both speaker and listener). The test shall be conducted with clothing, equipment and in the environment containing, receiving, and transmitting communication devices currently in use and those in use in the FY86 time period.

to shall conform to the guidelines on vision for aircraft as developed by aeromedical authorities. The lens shall be shatter, abrasion, and glare resistant and susceptible to fogging than applicable. Outserts, both clear and tinted, will be provided. The mask shall allow for or provide a method of correcting vision. A maximum effort will be made to satisfy protection requirements when the mask is worn over what spectacles; however, alternate methods of correcting vision may be necessary to avoid compromising protective devices. The mask shall allow the satisfactory use of standard optical devices such as binoculars and night vision devices. Also, it will be compatible with the sights of individual and crew-served weapons systems.

EVALUATION CRITERIA AND VALUES

PHYSICAL OPTICS

4.1 Luminous Transmittance (≥ 85 percent)

4.1.2 Haze: (≤ 5 percent)

4.1.3 Prismatic Deviation:

Vertical deviation not exceed 0.18 diopters and the algebraic sum and difference of the vertical deviation between the two center points must not exceed 0.50 and 0.18 diopters, respectively.

4.1.4 Refractive Power: (≤ 0.125 Diopters)

4.1.1 and 4.1.2 The measurement of light transmission shall be for the mask only. The measurement of light transmission for the combination of the mask and outserts shall be for information only.

Apparatus: Luminous Transmittance: Photo Research

Photometer, Model 1980 and a gamma scientific standard

Lamp, model RS-10 or equivalent.

Haze: Gardner hazemeter, model UX10, and Gardner

Digital photometric unit, model PG-5500 or equivalent.

4.1.3 American Optical Company focimeter which is calibrated for prismatic deviation units of 0.1 prism diopter and has a maximum range of 0.50 prism diopter. Measurements of vertical and horizontal deviation will be made at the center points.

4.1.4 American Optical Company focimeter which is calibrated in units of 0.01 diopter and has a maximum range of + 0.30 diopter. Mask will be positioned in focimeter approximately as worn and measurements are taken at the left and right center points.

4.1.5 An arbor optical tester using a 60-line grating. Optical distortion of the defined critical area of the test sample shall be determined by inserting the sample with its surface normal to the line of sight into the testing apparatus.

EVALUATION CRITERIA AND VALUES

.2 FIELD OF VISION (UNOBSTRUCTED)

Horizontal - No established criteria.

EVALUATION CONDITIONS AND PROCEDURES

4.2 Haag-Streit Perimeter. The target stimulus will be a high contrast 1mm diameter white light circle which is projected centered on a hemisphere at a distance of 33 cm from the test subjects eye. The stimulus luminance will be 54 foot lamberts against a background luminance of approximately 0.25 foot lamberts. Meridional measurements will be made monocularly for the left and right eyes at 15 degree intervals.

.3 REFLECTING GLARE AND GLINT

No established criteria.

.4 SHATTER RESISTANCE

No lens fractures or object penetration.

.5 COMPATIBILITY WITH CORRECTIVE SPECTACLES / OPTICAL INSERTS:

5.1 Spectacles/optical inserts shall not provide protection required by the masked wearer

.6 COMPATIBILITY WITH STANDARD OPTICAL DEVICES / WEAPONS SIGHTS

The mask shall provide satisfactory use with standard optical devices and those to be in the 1986 timeframe.

CHARACTERISTIC = RELIABILITY, AVAILABILITY, AND MAINTAINABILITY:

<u>Mean time between life threatening operational mission failure (MTBLTOMF) (hours)</u>	<u>Mean time to repair (MTTR) (minutes)</u>
1200	6
1870	3.7

EVALUATION CRITERIA AND VALUES

<u>EVALUATION CONDITIONS AND PROCEDURES</u>	
5.1. REUSABILITY (See protection requirements of Section 1). Criteria to be evaluated will be the separate protection characteristics of canister and mask to gas, biological, and liquid agents.	5.1. Applicable test procedures are as cited in Section 1.
5.2. DURABILITY	5.2. Applicable test procedures are as cited in Sections 1, 3, 4, 5, 6, and 10.
5.2.1. Mask Facepiece and Accessories. Overall objective is serviceability after 1 year of use.	5.2.1. One year of operational use is defined as a total of 150 hours of wear and carry accumulated in incremental periods not to exceed 12 hours each.
5.2.1.1. Permeation: Per sections 1.4.1 and 1.4.2.	5.2.1.1. Per sections 1.4.1 and 1.4.2.
5.2.1.2.1. Leakage: Per sections 1.2.1 and 1.3.2.	5.2.1.2.1. Per sections 1.2.1 and 1.3.2.
5.2.1.2.2. Leakage during drinking.	5.2.1.2.2. Per sections 1.3.2 and 10.4.
5.2.1.3. Drinking: Per sections 10.1, 10.2, and 10.3.	5.2.1.3. Per sections 10.1, 10.2, and 10.3.
5.2.1.4. Vision:	5.2.1.4. Per sections 4.1.1, 4.1.2, and 4.1.5.
5.2.1.5. Light Transmission Irradiance Optical Distortion	5.2.1.5. Per section 3.1.
5.2.1.6. Inhalation resistance: Per section 6.4.	5.2.1.6. Per section 6.4.
5.2.1.7. Exhalation resistance: Per section 6.5.	5.2.1.7. Per section 6.5.
5.2.1.8. Hardware Integrity: Head harness: Replaceable Radiation Valve - functional Voice emitter - functional Threaded connectors - functional Harness buckles - functional	5.2.1.8. Functionality shall be determined by visual inspection and compliance with specification requirements, as applicable.

EVALUATION CONDITIONS AND PROCEDURES

EVALUATION CONDITIONS AND PROCEDURES

2.2 C r

Required CT vapor protection:

aB 40,000 mg-min/m³ minimum

CK 20,000 mg-min/m³ minimum

AC 20,000 mg-min/m³ minimum

aerosol protection:

Biological - maximum 0.0002 percent penetration

Chemical Aerosol - maximum 0.010 percent penetration

Airflow resistance: Shall not exceed 45 mm H₂O
excluding physical immersion in liquid)

5. Applicable test procedures are as cited in sec.
1.

5.2.2.1 Artificial Aging: Canisters, without closure, shall be subjected to the following artificial aging conditions: 120 hours @ 240° + 0° - 5°F and ambient humidity.

Subsequent to aging the canisters shall be allowed to equilibrate to ambient temperature and humidity and shall meet or exceed the requirements of 11.1.

5.2.2.2 Accelerated rough handling: Unpackaged canisters shall be rough handled in a Q113 Rough Handling Machine or equivalent apparatus in accordance with MIL-C-10116B and ECP 522-029. Subsequent to rough handling, the canisters shall be subjected to visual inspection plus the following tests:

- a. GB and GD gas life.
- b. CK gas life.
- c. DOP and BG penetration.
- d. Airflow resistance.

EVALUATION CRITERIA AND VALUES

.3 CARE AND MAINTENANCE

The mask must be easily cleaned using field available substances without damage or deterioration of the mask material. The mask will be maintained at operator/organizational level.

ITR-MAV-6 min; BOC - 3.7 min.

JSOR CHARACTERISTIC - WEARABILITY/COMFORT:

Fully trained personnel not suffering from facial and head injuries shall be capable of wearing the mask for 12 hours while performing their assigned military duties under conditions of a moderate work rate (250-kcal/hr) temperate climatic conditions. Inhalation breathing resistance be no greater than 55 mm of water at 85 liters/minute (1pm) for the field version of the mask and no greater than 70 mm of water at 85 1pm for the aviation and combat vehicle masks with attached hoses. Exhalation breathing resistance will be no greater than 26 mm of water at 85 1pm. The face mounted portion of the protective mask shall weigh no more than 2.0 pounds.

EVALUATION CRITERIA AND VALUES

1 WEARING TIME

gilt 10-12 hours at medium work rate (250-kcal/hr).
dep for 8 hours while wearing mask. Perform common
military tasks.

2 WEIGHT

piece and canister: 2.0 lb maximum.
old mask, carrier, and accessories: 4.0 lb max.
aircrew mask, carrier, and accessories: 5.0 lb
maximum.

EVALUATION CONDITIONS AND PROCEDURES

5 Airflow resistance shall be determined under ambient conditions at a flow rate of 85 lpm using a Q112 Canister Resistance Indicator or equivalent apparatus.

5.3 Care and maintainability aspects will be determined in conjunction with compatibility and other wearing trials conducted at CONUS/OCONUS military installations by qualified test and evaluation personnel.

EVALUATION CONDITIONS AND PROCEDURES

6.1 Wearing trials will be conducted by troops at various CONUS and OCONUS installations.

6.2 Self-explanatory. Accessories are outsert and waterproofing bag.

TEST CONDITIONS AND VALUES

6.3 VE DEAD SPACE

Under normal activity, it shall not exceed 400 ml.

6.4 INHALATION RESISTANCE

55 mm H₂O (max) (45 mm desirable) for one canister system (field mask).

10 mm H₂O (max) for armor and aircrew mask.

6.5 EXHALATION RESISTANCE:

6 mm H₂O (max)

6.6 OPERATIONAL TEMPERATURE RANGE:

55°F to 120°F. There shall be no degradation in performance during wear within the temperature range. The criteria for performance of common military skills, as modified for the temperature environments, shall apply.

7 ALTITUDE CEILING:

Capable of being worn on flights (routine, enroute, and nap-of-the-earth (NOE)) up to but including altitudes requiring pressurized breathing.

JSOR CHARACTERISTIC - COMPATIBILITY:

The mask, carrier, and accessories shall be compatible with individual combat clothing, protective headgear, aircraft compatibility, pressure point (hot spots) caused by the interface of the man-mask-helmet shall be reduced. It is recognized that the AH-64 Attack Helicopter requires a unique protective mask. The total weight of the mask, carrier, and mask accessories should be as light as possible but shall not exceed 4.0 pounds (5.0 pounds c/w contact with exposed wiring and circuitry). The mask shall not damage equipment or present a shock hazard to personnel who must work in

EVALUATION CONDITIONS AND PROCEDURES

6.7 Methods described in CWLR 2264 or equivalent will be utilized. The trials will be conducted at U.S. Army Research Institute of Environment Medicine, Natick, MA.

6.4 Airflow resistance shall be determined using ambient conditions at a flow rate of 85 lpm using Q-213 Inhalation/Exhalation Resistance Indicator or equivalent apparatus.

6.5 Airflow resistance shall be determined under ambient conditions at a flow rate of 85 lpm using Q-213 Inhalation/Exhalation Resistance Indicator or equivalent apparatus.

6.6 Methods defined in test agency's test design plan will be utilized.

6.7 Tests shall be conducted in an altitude chamber or under actual flight conditions.

EVALUATION CRITERIA AND VALUES

1 COMPATIBILITY

Mask, carrier, and accessories must be compatible with all clothing and equipment used by combat, crew, and armor personnel to perform their missions. The mask must be adapted to the oxygen (see 6.7) supply and communications equipment in aircraft and to the air supply and communications equipment in combat vehicles.

2 ADAPTABILITY

The mask shall be adaptable to self-contained fire support systems to extend operations.

3 WEIGHT

See Section 6.2.

JSOR CHARACTERISTIC - RUGGEDNESS, ACCESSIBILITY, AND FIT:

The mask shall provide a positive fit while the individual performs assigned military duties. When the mask is in use, it should be protected by the carrier from most hazards likely to be encountered in operational situations. The mask will be readily accessible to the individual (whether standing, sitting, kneeling or prone) so that it can be donned within 9 seconds by properly trained personnel. The mask design shall allow the fit of the 5th percentile (female) to the 95th percentile (male). Provision will be made to permit the protective mask in carrier to be immersed in water for periods up to five minutes without damaging the protective mask.

EVALUATION CRITERIA AND VALUES

RUGGEDNESS

EVALUATION CONDITIONS AND PROCEDURES

8.1 Rigorous wearing trials will be conducted at CONUS and OCONUS military installations.

EVALUATION CRITERIA AND VALUES

EVALUATION CONDITIONS AND PROCEDURES

.1.1 The mask is not in use, it should be protected by the carrier and a rigid lens outsert from most hazards likely to be encountered in the field.

.1.2 During carrying or wearing; the mask, carrier, and component parts shall withstand the normal wear and tear incident to combat conditions and still provide adequate protection:

Mask Leakage: 0.003 percent max DOP penetration.
Mask Airflow Resistance: 55 mm H₂O (max).

Canister Gas Life:

GB - 40,000 mg-min/m³, minimum
CK - 20,000 mg-min/m³, minimum
DOP - 0.010 percent maximum

.1.3 The mask, facepiece, carrier, and mask component parts shall not corrode or support moldew growth when exposed to various environmental conditions.

.1.3.1 thru 8.1.3.5 Masks shall remain functional when tested to criteria cited in Section 5.2.

.1.3.2 Minimal corrosion; shall not affect functionability.

.1.3.3 Minimal growth, shall not affect functionability.

8.1.3 Fungus - MIL-STD-810D, Method 508.3.

8.1.3.4 Rain - MIL-STD-810D, Method 506.2, Procedure II.

8.1.3.5 Dust - MIL-STD-810D, Method 510.2, Procedure I.

6 and 8.1.2 Masks without protection from the carriers or outserts will be subjected to 25 six-foot drops onto a hard surface. Also, masks with carriers will be tumbled in the Q113 rough handling machine for 25 complete revolutions. After the above tests, a visual inspection shall show the masks to have no more degradation than that of the M17A1 masks. Also, applicable test procedures cited in Sections 1 and 6 shall apply. The mask shall be tested for aerosol leakage using an M14 Mask Leakage Tester or equivalent apparatus.

.1.4 During carrying or wearing; the mask, carrier, and component parts shall withstand the normal wear and tear incident to combat conditions and still provide adequate protection:

8.1.3 The following tests shall apply:

8.1.3.1 Salt Fog - MIL-STD-810D, Method 509.2, Procedure I, 48 hours @ 95°F.

8.1.3.2 Sunshine - MIL-STD-810D, Method 505.2, Procedure I, 6- to 8-hour exposures.

8.1.3.3 Fungus - MIL-STD-810D, Method 508.3.

EVALUATION CRITERIA AND VALUES

1.4 The mask shall not be damaged and will remain functional after being immersed in 3 feet of water for 5 minutes in a carrier. No visual evidence of water shall be shown on the masks or the waterproofing bag. Also, the airflow resistance of the mask shall not exceed a maximum of 55 mm H₂O.

2 ACCESSIBILITY

The mask shall be designed so that the mask can be donned, whether standing, sitting, kneeling, prone within 9 seconds by properly trained personnel.

3 FIT

3.1 Under normal stress of combat, the mask shall provide a positive fit. Any physiological symptoms (tearing, coughing, etc.) experienced / the test subject attributed to corn oil and / will be considered a failure.

3.2 The mask shall fit the 5th percentile male to 95th percentile male based on soldier's face width and length. Fit will be verified by leakage criteria for a new mask using corn oil aerosol.

EVALUATION CONDITIONS AND PROCEDURES

8.1.4 Masks will be placed in their waterproofing bags and placed in their carriers. After immersion in 3 feet of water for 5 minutes, the masks will be visually inspected and tested for airflow resistance as cited in Section 6.

8.2 Time for protection will be the time from recognized alert to clearing of the mask as determined by trials with properly trained troops.

8.3.1 Chamber exercises will be conducted at CROC. In field exercises, applicable Sops/Field Manuals will be utilized for dissemination instructions of CS.

8.3.2 Large-scale male-female fitting trials will be conducted using the TM fit, that is, checking the mask, and also a gas tight fit using isoamyl acetate. Verification of fit will be made by leak testing with corn oil aerosol (para 1.3.2). A panel of people representing the population shall be fitted in the trials.

JSOR CHARACTERISTIC = SURVIVABILITY:

Nuclear and NBC contamination survivability are required. At temperatures and at rates of thermal loading at which a human would survive, the mask must be fire resistant, not melt, and not release toxic vapors. The mask/hood system will be resistant to the absorption of liquid chemical agents. The mask shall be capable of being initialized or quickly and readily decontaminated by the individual in the field using available decontaminants without reducing the protective capability of the mask. A liquid agent resistant hood to protect the facepiece and head and neck areas from CB agents, and which is easily and nondestructively removed, shall be provided.

EVALUATION CRITERIA AND VALUES

1 DECONTAMINATION

1.1 No residual surface contamination shall be evident for mustard (HD) or thickened Soman (TGD).

1.2 Agent Permeation:

Mustard (HD): 360 minutes, minimum

Thickened Soman (TGD): 360 minutes, minimum

1.3 Physical Optics:

Luminous Transmittance: (\geq 85 percent)

Haze: (\leq 5 percent)

2 SANITIZATION

2.1 Cleanliness. Customary sanitary standards shall be achieved.

2.2 Physical Optics:

Light transmission: \geq 85 percent

Haze: \leq 5 percent

3 Nuclear Effects Challenge:

blast, neutron fluence, and thermal.

EVALUATION CONDITIONS AND PROCEDURES

9.1.1 Facepiece shall be contaminated according to procedures in para 1.4.1. The agents should remain on the surface 5 minutes. After the 5-minute period, the samples are decontaminated according to procedures described in the draft XM40 manuals and tested for any residual contamination using the appropriate standard liquid agent detector papers.

9.1.2 After being decontaminated or sanitized (see para 9.2.1), items shall be agent tested according to the test criteria of para 1.4.1.

9.1.3 The lens area of the mask, not including outsert, after being decontaminated or sanitized (see para 9.2.1) shall be tested and meet the vision requirements when tested per Sections 4.1.1, and 4.1.2.

9.2.1 Facepieces shall be sanitized according to accepted procedures described in the draft XM40 manual.

9.2.2 Facepieces shall be sanitized according to accepted procedures described in the draft XM40 manuals and tested for vision requirements of Sections 4.1.1, and 4.1.2.

9.3 Criteria, conditions, and procedures defined in White Sands Missile Range test plan, dated 25 Jul 84.

condition, the mask will provide the wearer with a drinking capability from the canteen.

EVALUATION CRITERIA AND VALUES

10.1 RATE OF DRINKING

One quart in 11 minutes.

10.2 WATER INTAKE

Shall begin no more than 15 seconds following initiation of mouth-generated sucking pressure.

10.3 DEVICE PREPARATION TIME

No more than 2 minutes

10.1 and 10.2 Subjects will be used to measure the preparation time and to obtain the required rate of drinking and water intake during field trials. The drinking device shall be capable of operating in temperatures above 32°F to a maximum of 120°F.

10.4 PROTECTION

Aerosol leakage: 0.015 percent maximum

10.3 Preparation time will be the time it takes a subject to detach the drink tube fitting from the mask and properly insert it into the canteen drinking cap. The mask will be on the face and the canteen in its carrier at the start. The operations will be accomplished both with and without environmental and CB protective handwear, excluding arctic mittens.

1. JSOR CHARACTERISTIC - STORAGE:

The packaged mask shall remain serviceable, and the protective capacity of the packaged filter shall not degrade more than 10 percent below the protection requirements stated in paragraph 1 for a minimum of ten (10) years of storage in climatic design types hot through severe cold as defined in AR 70-38, 1 Sep 79.

EVALUATION CRITERIA AND VALUES

.1	CA, -R	<u>Agent Required Ct</u>
CB	270,000 mg-min/m ³	
GD	270,000 mg-min/m ³	
AC	36,000 mg-min/m ³	
CK	36,000 mg-min/m ³	

sol Penetration:

Chemical/Radiological: 0.010 percent, maximum
airflow Resistance: Shall not exceed 45 mm H₂O.

EVALUATION CONDITIONS AND PROCEDURES

11. Conditioning of canisters will not be on a real time basis because of the mission length. Evaluation will be on an indicative basis only unless degradation can be accurately modelled. Applicable test procedures are as cited in Section 1. The following tests shall be performed as simulations of extremes of environmental storage:

11.1.1 Accelerated Storage:

Packaged canisters shall be subjected to the following accelerated storage conditions for periods up to 12 weeks.

- (T) Tropic - 113°F @ 85 percent relative humidity
- (D) Desert - 145°F
- (TE) Temperate - Ambient, unconditioned environment at Edgewood Area, APG.
- (A) Arctic - -50°F
- (C) Cyclic - Rotation of items through the above storages at 1-week intervals as follows: D-A-T-D-A-T-etc.

Subsequent to storage, the canisters shall be subjected to the following tests:

- a. Visual inspection for evidence of damage, corrosion, mildew, etc.
- b. Weight gain or loss.
- c. DOP and BG penetration.
- d. Airflow resistance.
- e. GB and GD gas life.
- f. CK gas life.

Accelerated surveillance tests will be supplemented by real time storage tests.

EVALUATION CRITERIA AND VALUES

EVALUATION CONDITIONS AND PROCEDURES

11.1.2 Accelerated Packaged Rough Handling: Packaged canisters shall be rough handled per MIL-STO-810C subsequent to storage in the environments listed in 11.1.1, as follows:

- a. Altitude per Method 500, Procedure I (except Step 2 shall be 5.00 in Hq and Step 3 shall be deleted).
- b. Vibration per Procedure XI.
- c. Shock per Method 516.2, Procedure II, Drop Height: 5 feet.
- d. Bounce per Method 514.1, Procedure XI, Para 2.

Subsequent to rough handling, the canisters shall be subjected to the tests outlined in 11.1.1 (a-f).
11.1 Applicable test procedures are as cited in Section 1, 2, 3, 4, 6, and 10.

11.2 FACEPIECE AND ACCESSORIES

The facepiece and accessories must remain serviceable as specified in Section 5.2.1.

2. JSOR CHARACTERISTIC - CLIMATIC CONSIDERATIONS:

The mask will be operational in climatic design types hot and basic as defined in AR 70-38, 1 Sep 79. A winching accessory may be provided, if required, to achieve operational capability within this range.

EVALUATION CRITERIA AND VALUES

2.1 The mask shall be capable of operating over a temperature range of -25°F to 120°F and all relative humidities. Evaluation criteria are as cited in Sections 1 through 11.

EVALUATION CONDITIONS AND PROCEDURES

12.1 Tests will be conducted at various CONUS and OCONUS military installations to evaluate operational efficiencies at the cited climatic conditions.

APPENDIX B

BIBLIOGRAPHY

PATENT DISCLOSURE FOR MULTI-LAYER MASK

BIBLIOGRAPHY FOR MULTI-LAYER MASK FINAL REPORT

Battelle Reports

Novel Seals and Specialty Component Attachment Mechanisms for Respiratory Protection System 21 (RESPO 21), October 1990

Master Control Unit (MCU), Low Cost Display (LCD) and Automatic Valving Systems for Respiratory Protection System 21 (RESPO 21), October 1990

Evaluation of a Lens Defog in a Protective Mask, January 1991

The Evaluation of Component Prototyping and Reverse Engineering Systems, November 1990

Electronics

December 1989 Progress Report on NBC Protective Mask Minature Motor Blower by Anatole J. Sipin Company, Inc.

The MCU-2/P Chemical-Biological Mask Microphone Improvement Task, Excerpt from report, Microphone Voicemitter Section, Involves Placing Microphone inside the Mask

Communication System, Overview, Develop an Improved Communications System that will allow a Microphone to be Connected to the XM40 Mask without Component Leakage Testing Check-out

Excerpt of Data on Intelligibility Scores for MCU-2/P Mask

M40 Voice Communication Overview

Excerpt of Data on Intelligibility Scores for M17 Mask with and without Loudmouth Speech Amplification Unit

Contract Modification Proposal for Phase II Development of a Blower to be used with a New NBC Protective Mask, January 10, 1991 by Anatole J. Sipin Co. Inc.

Speech Intelligibility Performance Using the M40 and XM44 Protective Masks Equipped with an Amplified Voicemitter Attachment, July 13, 1990 by Richard W. McMahon, Kate Stemann

Memorandum for Record, Technology Survey Results (Valve/Air Management)

Chemically Bonded Ceramic Tooling for Rapid Prototyping, by Sean Wise, CEMCOM Research Associates

Optics

Field of Vision Test Data, Attachment 31, Final Report, February 28, 1983, Tests on FOV of M17A1, JSAM 5.7 Mockup and JSAM 5.7 Molded Mask

Test Report, CSL, Design Concepts in C.B. Protective Mask

Excerpt from report on the design study to develop a XM40 single lens mask (SLM).

Lens Discussion, General considerations and guidelines for design of lenses for protective facemasks.

Visual Survey of Infantry Troops, Part I: Visual Acuity, Refractive Status, Interpupillary Distance, and Visual Skills by David J. Walsh, Sensory Research Division, June 1989

Handbook of Optics, Driscoll, W. G. , Vaughan, W. . 1978

Clinical Optics, Fannin, T.E., Grosvenor T. , 1987

PATENT DISCLOSURE
MULTI-LAYER PROTECTIVE MASK
MAY 1990

1. What problem does your invention solve?

Several problems are solved with this invention of a Multi-layer Protective Mask, they are:

- a. Decontamination.
- b. Hood System - Liquid Agent Protection.
- c. Recognition.
- d. Comfort/Fit.
- e. Field-of-View
- f. Optical Coupling/Weapon System Compatibility.
- g. Optical Correction and Laser Protection integration.
- h. Facial Protection.
- i. Breathing resistance.
- j. Heat burden.
- k. Communications.

How long has the problem existed?

These problems have existed since the onset of the development of the Chemical/Biological (CB) protective mask, which occurred since World War I.

Ronald H. Gutekunst
WITNESS

3/24/90
DATE

Robert R. Lafferty
INVENTOR

135-281
DATE

John M. Gutekunst
WITNESS

3/24/90
DATE

Robert R. Lafferty
INVENTOR

135-281
DATE

2. What old ways are available for solving the problem?

The old ways available for solving the problems (listed in para 1) have been many since World War I. Described below are the methods implemented in the Army's most current protective mask, the M40 series mask.

NOTE: The M40 mask is a series of masks which includes masks intended for use by the infantry (the M40) and masks intended for tankers use (the M42).

a. Decontamination.

The M40 is covered by a protective hood which is removed from mask during decontamination. Both the hood and the mask must undergo extensive cleaning prior to reissue.

b. Hood System - Liquid Agent Protection.

The M40 is covered with a thin butyl coated nylon hood which offers six hours of liquid agent protection.

c. Recognition.

The M40 has no provisions for wearer recognition which must be handled through local Standard Operating Procedures.

d. Comfort/Fit.

A silicone facepiece which has an interned peripheral seal provides a comfortable seal on the face in the M40 series of masks.

e. Field-of-View.

The M40 has two large lenses to provide field-of-view.

f. Optical Coupling/Weapon System Compatibility.

The M40 has a closer eye relief than the previous mask (M17) for optical coupling with optical sighting devices and can mount the filter on either side of the face to accommodate rifle firing.

Robert H. Zelinski
WITNESS

12 Dec 90
DATE

Robert R. Taff
INVENTOR

13 Jan 90
DATE

William A. Gaskins
WITNESS

12 Dec 90
DATE

Wayne J. Jones
INVENTOR

13 Jan 90
DATE

g. Optical Correction and Laser Protection Integration.

Optical correction is provided by mounting spectacles in the mask and laser protection is offered by outsert caps mounted with a rubber boot attachment over the primary lenses.

h. Facial Protection.

Facial protection from chemical agents is offered by the silicone faceplate covered by a butyl coated cloth hood. No facial ballistics protection is available.

i. Breathing Resistance.

The M40 incorporates low resistance flapper valves to provide an acceptable breathing resistance.

j. Heat Burden.

The M40 mask provides for no heat burden relief.

k. Communications.

A front voicemitter in the M40 provides face-to-face communications, a side voicemitter is for telephonic communications, and in the M42 (tankers version), a hook-up is provided to connect into the on-board communications system.

3. Why are the old ways unsatisfactory for solving the problems?

The old ways for solving the problems were unsatisfactory for the following reasons (These reasons correspond to the ways that the M40 solved the problems, as stated in para. 2):

a. Decontamination.

The M40 requires deliberate decontamination of both the mask and the hood assembly.

John J. Taffi
WITNESS

13 Jun 90
DATE

John J. Taffi
INVENTOR

13 Jun 90
DATE

William M. Galt
WITNESS

13 Jun 90
DATE

John J. Taffi
INVENTOR

13 Jun 90
DATE

b. Hood System - Liquid Agent Protection.

The M40 is limited to six hours of liquid agent protection because of the faceplate is of silicone in order to provide a comfortable seal (silicone provides little or no liquid agent protection) and the agent resistance of the thin butyl hood covering is limited to six hours. The hood thickness is minimized in an effort to prevent compatibility problems with the helmet.

c. Recognition.

The M40 has no provisions for wearer recognition.

d. Comfort/Fit.

The lack of comfort is a product of several factors in the M40 mask. The suspension system has thick strapping and metal buckles which cause hot spots on the users head. The hood is not conformal and is bulky which causes movement to be awkward. The combined weight of the mask, hood and canister on the head causes neck strain. The relatively heavy filter bounces when the user moves quickly, causing the mask to jerk the head of the wearer.

e. Field-of-View.

The M40 provides a limited binocular field-of-view due to the lenses being too far from the eye of the user. Lookdown capability is a common problem encountered.

f. Optical Coupling/Weapon System Integration.

Due to the eye relief of the M40 being 45 millimeters, many sighting devices within the Army inventory either cannot be used or the field-of-view is significantly reduced. The eye relief typically required is 25 mm. The filter canister since it is located on the facepiece, also poses compatibility problems with weapon systems.

William A. Hart
WITNESS

13 June 90
DATE

John P. T. Hart
INVENTOR

13 June 90
DATE

William A. Hart
WITNESS

13 June 90
DATE

John P. T. Hart
INVENTOR

13 June 90
DATE

g. Optical Correction and Laser Protection Integration.

The method employed by the M40 mask to provide optical correction is unsatisfactory due to the "spectacles in the mask" concept. This concept does not integrate the optical correction into the mask. Also, the lenses are too small and located too far from the eye of the wearer. For laser protection the M40 uses an outsert which is attached over the crimping ring for the mask's primary lenses. This raises the eye relief even further from what was already an unsatisfactory eye relief.

h. Facial Protection.

The M40 has no special provisions for facial protection against fragments although the silicone faceplate provides limited protection against the elements, branches, etc.

i. Breathing resistance.

The flapper type valves could be redesigned or replaced by lower resistance valves. The C2 canister (which is the filter used with the M40) has a 45 mm of H₂O resistance when measured at 85 lpm. which could be improved with an alternate filter design. Both inhalation and exhalation resistances should be reduced by a factor of 2 to satisfy physiological goals.

j. Heat burden.

The hood and mask system is comprised of impermeable materials which encapsulate the head, neck, and shoulders of the wearer. This combined with the encapsulation of the body can quickly result in a heat stress situation. The build-up of moisture adds to the discomfort of the wearer.

k. Communications.

Intelligibility is not at an acceptable level when speaking through the current voicemitter. Modified Rhyme Tests (MRT) indicate that the scores of 75% are typical of the M40 masks. Human Engineering goals of have indicated that a scorer of 91% is the minimum needed for adequate communications.

Kirk J. M. Burchell
WITNESS

2 Jun 90
DATE

W. W. P. T. M. Jr.
INVENTOR

13 Feb 90
DATE

John M. K. Jr.
WITNESS

2 Jun 90
DATE

John M. K. Jr.
INVENTOR

13 Feb 90
DATE

4. What are the new results and advantages of your invention?

NOTE: The following results and advantages correspond to the RESPO 21 Multi-layer concept.

a. Decontamination.

The new design greatly facilitates the amount of cleaning needed during decontamination by providing a removable faceplate cover which has greater agent resistance than the M40. This cover can be decontaminated to an adequate level with hasty decontamination which allows removal from the wearer. Deliberate decontamination/disposal of this mask is accomplished with greater ease.

b. Hood System - Liquid Agent Protection.

The outer layer cover provides at least a 24 hour liquid protection capability. The design facilitates the addition of such a cover since the seal does not have to be of the same material as in the M40 design. This design allows materials of different hardness/stiffness to be attached.

c. Recognition.

Wearers can be recognized since the facepiece is relatively clear in the normal operating mode.

d. Comfort/Fit.

Additional comfort is provided by removing the heavy strapping utilized in the M40 design. Also, the seal and nosecup are made of a highly conformal encapsulated gel for maximum comfort. Air can be pumped into the seal for even better fit and comfort.

e. Field-of-View.

The lens system is much larger than that of the M40. The lens is designed to allow for vision across the nose bridge to significantly improve the binocular field-of-view of the wearer. A lookdown capability is provided by moving the lens closer to the eye and extending the lens in the cheek area. Improved peripheral vision is applied with side visors.

John H. Dill
WITNESS

13 Jun 90
DATE

John H. Dill
INVENTOR

13 Jun 90
DATE

John H. Dill
WITNESS

13 Jun 90
DATE

John H. Dill
INVENTOR

13 Jun 90
DATE

f. Optical Coupling/Weapon System Integration.

The lens system is moved closer to the eye to maintain a maximum eye relief of 25 mm which meets the stand-off requirements of almost all sighting devices and weapons. By improving the vision in the nose bridge area, rifle firing can be accomplished more easily.

g. Optical Correction and Laser Protection Integration.

The lens system is specifically designed to allow for the stacking of lenses. The system is essentially a flat lens system which allows the lenses to be placed as close as possible to the eye even in the stacked configuration. The front and back curves of each of the lenses (optical correction, primary, and laser) are matched to reduce stand-off distance and to minimize prism effects caused by the use of multiple lenses.

h. Facial Protection.

An optional rigid (hardshell) faceplate is being provided for limited fragment protection of the face. This can be snapped over the outside of the faceplate while allowing the other features of the system to function normally. Compatibility with weapons and sighting devices is maintained because the configuration of the faceplate has been tailored to maintain compatibility while in the hardshell mode.

i. Breathing resistance.

Breathing resistance is greatly reduced by providing a small motor blower device that circulates air through the filter and into the facepiece. This air assists breathing during inhalation and is routed to the exhalation valve via a pressure monitoring device to reduce exhalation resistance.

j. Heat burden.

Heat burden is reduced by circulating air into the hood region of the respiratory system promoting moisture evaporation and convective cooling.

D. L. J. M. Fletcher
WITNESS

13 Jun 90
DATE

William M. Fletcher 13 Jun 90
INVENTOR DATE

William M. Fletcher
WITNESS

13 Jun 90
DATE

John P. Ferguson 13 Jun 90
INVENTOR DATE

k. Communications.

The system utilizes a redesigned voicemitter for passive operations which helps eliminate vibration and has a broader frequency range. For scenarios where communications are critical, a small amplifier is supplied which snaps into the front of the voicemitter assembly and connects into the microphone already supplied for electronic communications in vehicles. Speech intelligibility is increased in this mode. An adapter for communicating in different vehicles is also provided.

Richard A. Fitch
WITNESS

13 Jun 81
DATE

William M. Fitch
INVENTOR

13 Jun 81
DATE

William M. Fitch
WITNESS

13 Jun 81
DATE

Key M. Fitch
INVENTOR

13 Jun 81
DATE

5. Description of numbered elements - Multi-Layer Protective Mask

1. Hood/Suspension System - The hood/suspension system is made of a coated fabric which is stretchable to provide a secure fit and to provide uniform tension on the seal of the mask. The coating is made of a latex or fluoropolymer material and provides liquid agent resistance of at least 24 hours.

2. Multi-Layer Facepiece - The multi-layer facepiece is made of three distinct layers which are mechanically attached. The mechanical attachments allow the layers to move freely without separation. This is necessary to allow the use of materials having different stretch and modulus characteristics in each layer. The outer layer contains the most rigid of the materials (ie. fluoropolymer) to provide the highest possible liquid agent protection. The intermediate layer (ie. urethane) provides the structural support and shape of the facepiece. The inner layer (ie. siliconè) is made of the softest material and provides for the soft face contact and sealing properties of the system. All layers are transparent to allow for user recognition not available in the M40.

3. Multi-Layer Lens System - The multi-layer lens system is also made of three distinct layers. The outer layer is a rigid material (ie. coated polycarbonate) which provides impact protection of the eyes. Coatings for laser eye protection can also be applied to this material. The outer layer can easily be replaced if damaged or if another type of coated lens is needed based on the operational scenario. The intermediate lens (ie. urethane) again provides the structural support and is integrated with the facepiece to prevent vapors from leaking into the mask system. The inner layer is used to support optical correction for the wearer. The inner layer can easily be snapped in or out to allow for different prescriptions. All layers are built to match the inner and outer curves of the lenses and to allow easy replacement.

John R. Pritchard
WITNESS

12/16/95
DATE

Allan M. Ziegler
INVENTOR

13 Jan 96
DATE

John R. Pritchard

12/16/95
DATE

Allan M. Ziegler
INVENTOR

13 Jan 96
DATE

4. Seal/Ducting System - The seal/duct system is formed between the intermediate and inner layer of the facepiece. This approach allows for seal contours and low profile ducting that are not available in the M40. Materials such as foam, silicone gels, or air sandwiched between these two layers and at the appropriate locations maximize sealing and comfort in the mask.

5. Blower/Filter System - A small low profile blower/filtration system is utilized for breathing assistance, air circulation, and to help prevent high pressure drops in the mask. Ambient air is circulated through a small circulating fan and low profile fabrics impregnated with activated charcoal to provide protection. The fabrics are embedded in the front bib of the mask. The blower can also be detached and the mask will remain operational (unblown mode). An option to the fabrics is to utilize a low profile filter system in which the particulate filter and charcoal are in separate compartments similar to the current M40 filter. The compartments would be separated to spread out the filter design thus achieving the lowest possible profile.

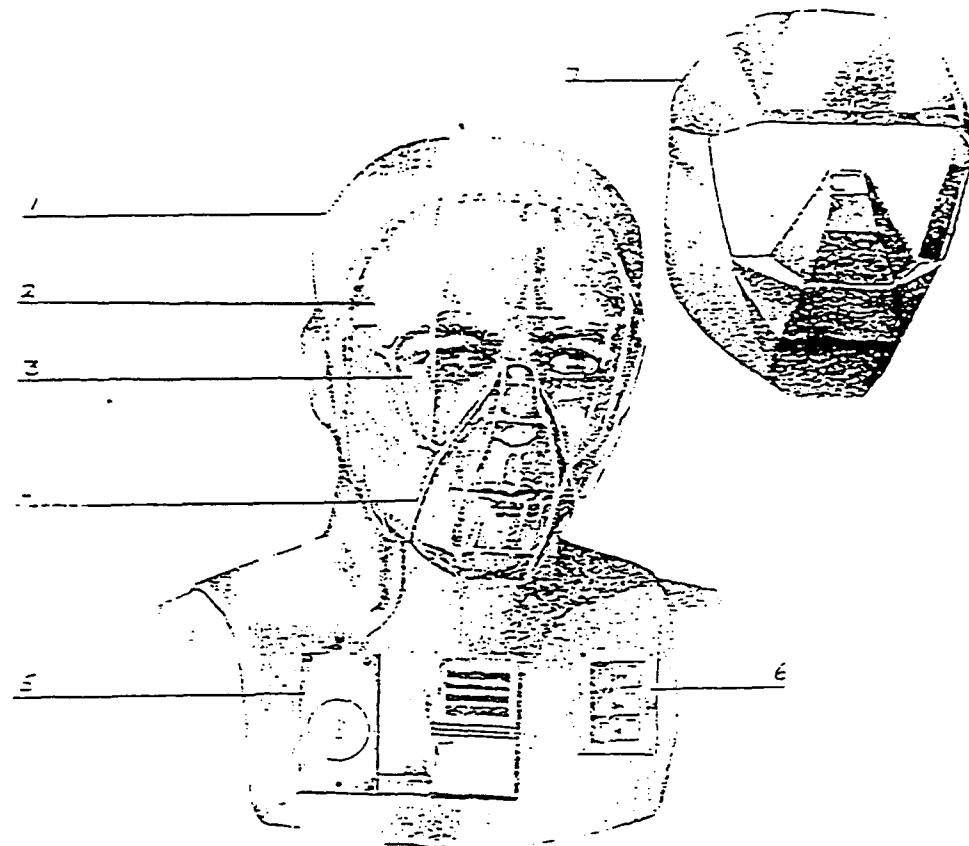
6. Control Unit/Communications - A control unit is provided to monitor the pressure drop in the mask and adjust airflow characteristics in the mask. This control unit allows for manual or sensor controlled adjustments to both valving and to the blower. Control and power of the communication system is also a function of this control unit. Communications is normally provided through a piezoelectric microphone and through a miniature amplifier/speaker system. An adapter cord is provided for hooking the microphone into field radio systems. A small speech diaphragm can also be provided for aided speech transmission without power.

7. Optional Ballistics Faceplate - A optional rigid faceplate is provided for limited fragment protection of the face. The faceplate is designed to fit over the outermost layer of the facepiece. The sides of the faceplate are contoured to facilitate rifle compatibility during firing.

RELEASABLE	BY	MARSHALL	13 JUN
WITNESS	DATE	INVENTOR	DATE

RELEASABLE	BY	MARSHALL	13 JUN
WITNESS	DATE	INVENTOR	DATE

MULTI-LAYER PROTECTIVE MASK



Edmund M. Lederle
WITNESS

13 June 90
DATE

William P. T. Murphy
INVENTOR

13 June 90
DATE

William M. Lederle
WITNESS

13 June 90
DATE

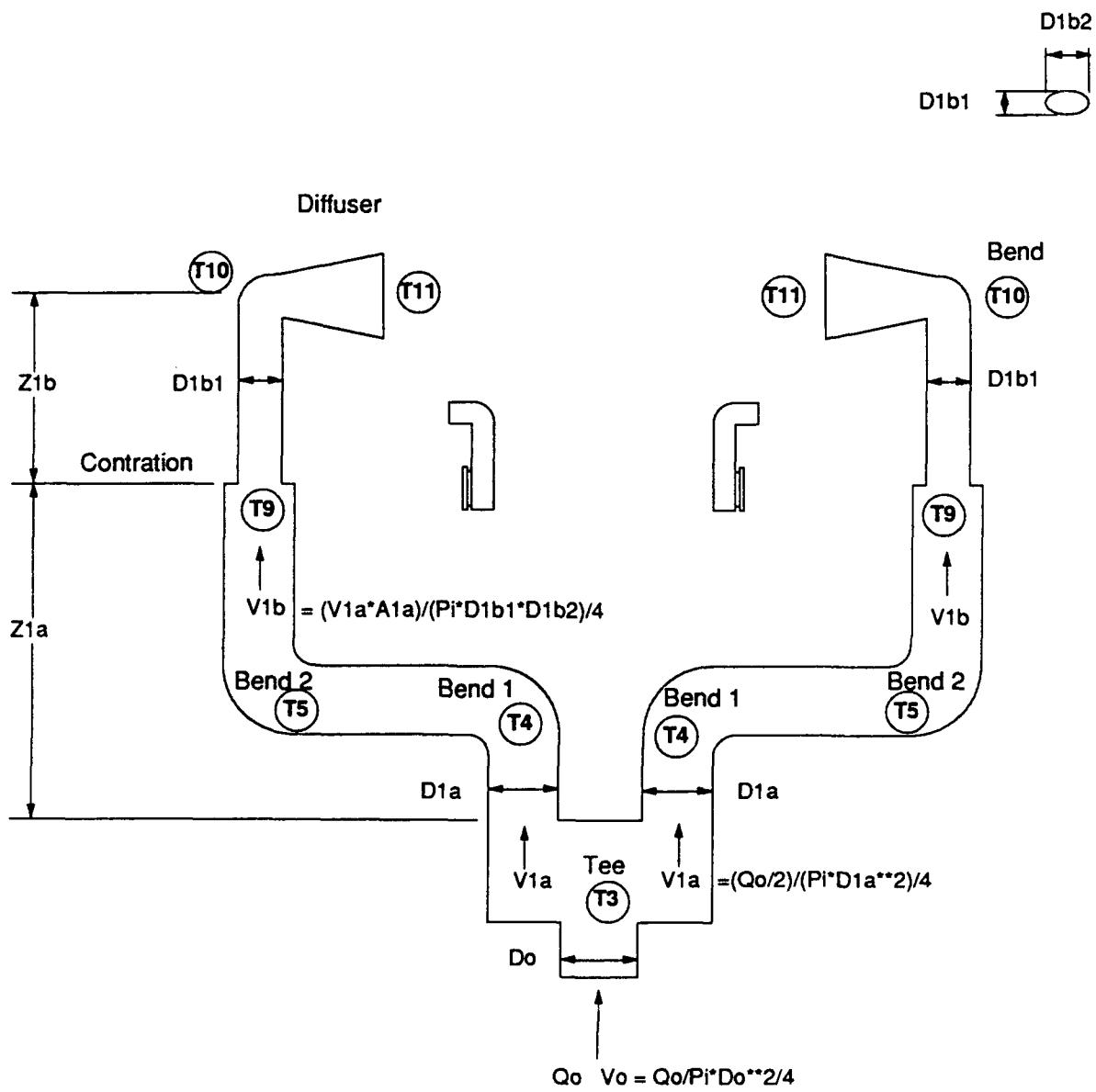
James J. Murphy
INVENTOR

13 June 90
DATE

APPENDIX C

AIRFLOW SCHEMATIC
PRESSURE DROP CALCULATIONS

Schematic of Airflow in Mask



Flow Calculations (85 lpm)

Inlet Flow	Q_0	85.0 lpm	0.0500 ft ³ /sec	
density	ρ	0.0752 lb/ft ³		
viscosity	ν	1.56E-04 ft/sec		
gravity	g	32.2 ft/sec ²		
inlet tube dia	D_0	1 in	0.0833 ft	
inlet tube x-section area	$A_0 = \pi(D_0 \cdot D_0)/4$	0.0055 ft ²		
inlet velocity	$V_0 = Q_0/A_0$	9.17 ft/sec		
Number of Inlet tubes	n	2		
neck tube height	z_{1a}	7 in	0.5833 ft	
neck tube dia	D_{1a}	0.5 in	0.0417 ft	
neck tube x-section area	$A_{1a} = \pi(D_{1a} \cdot D_{1a})/4$	0.0014 ft ²		
Neck tube velocity, each tube	$V_{1a} = Q_0/(n \cdot A_{1a})$	18.35 ft/sec		
Reynold's number (neck tube)	$Re_{1a} = (V_{1a} \cdot D_{1a})/\nu$	4900		
From Fig 8.14 page 362*	use Re_{1a} and smooth pipe curve to find	0.0215		
From Table 8.3 page 371*	use standard 45deg elbow to find (L_e/D)	16		
From Table 8.3 page 371*	use standard 45deg elbow to find (L_e/D)	16		
From Table 8.3 page 371*	use flow thru branch tee to find (L_e/D)	60		
ellipse height	z_{1b}	6.4 in	0.5333 ft	
ellipse d1	D_{1b1}	0.3125 in	0.0260 ft	
ellipse d2	D_{1b2}	0.75 in	0.0625 ft.	
ellipse x-section area	$A_{1b} = (\pi \cdot D_{1b1} \cdot D_{1b2})/4$	0.0013 ft ²		
ellipse perimeter	$P = \pi((D_{1b1}/2) + (D_{1b2}/2))^2 \cdot \nu \cdot a_l$	0.1391 ft		
ellipse De	$D_e = 4 \cdot A_{1b}/P$	0.4411764 in	0.0368 ft	
Reynold's number (ellipse)	$Re_{1b} = (V_{1b} \cdot D_e)/\nu$	19.57 ft/sec		
From Fig 8.14 page 362*	use Re_{1a} and smooth pipe curve to find	0.038		
From Table 8.3 page 371*	use standard 90deg elbow to find (L_e/D)	20		
From Fig 8.17 page 367*	fitting AR = $A_2/A_1 = A_{1b}/A_{1a}$	0.9375		
	Use AR and contraction curve to find K	0		

Flow Calculations (85 lpm)

From ASHREA** page 31.31 table4.7	Use Th = 33deg	A1/A0 = 1.61 to find C	0.2	
Perimeter Calc				
b = minor D/2	0.0130208			
a =major D/2	0.03125			
m = (a-b)(a+b)	0.000807			
Val = 1 + (m)2/4	1.0000002			

*Fox, R.W., McDonald, A.T., *Introduction to Fluid Mechanics*, Third Edition, John Wiley and Sons, New York

**ASHRAE Handbook of Fundamentals, 1977

APPENDIX D

QUOTATION FROM AMERICAN OPTICAL



American Optical Corporation

SOUTHBridge, MASSACHUSETTS, U.S.A. 01550 / (508) 765-9711

cc: T.Campbell
T.Hill
G.Wilson

: 23 May 1991

Mr. Thomas A. Pettenski
BATTELLE
505 King Avenue
Columbus, Ohio 43201-2693

Re: Proposal for Design Evaluation

Dear Mr. Pettenski:

American Optical's Precision Products Division is pleased to respond to your Request for Quotation dated 6 May 1991. The enclosed proposal includes a Technical Discussion and Cost Analysis for a design evaluation effort on a three lens optical system for a protective mask. The results of this evaluation will include detailed analysis results and recommendations for design optimization.

In order to perform a detailed analysis, please furnish as much specific information as is available at the time of award.

If you have any questions or need further information, please contact me.

Sincerely,
AMERICAN OPTICAL CORPORATION

A handwritten signature in black ink that reads "Clark L. Grendol".

Clark L. Grendol
Director, Product & Process Engineering
Precision Products Business

CLG/d
Enclosure

cc: J.L.Bala
R.W.Heath
J.D.Masso
A.J.Philla
R.J.Tillen

TECHNICAL PROPOSAL

1.0 Purpose:

This Technical Proposal details the work effort that American Optical Corporation, Precision Products Business (AOPPB) proposes to perform for Battelle in evaluating an optical lens system for a new protective mask.

2.0 Objective:

The evaluation of this lens system will consist of a strict optical evaluation and a mechanical evaluation pertaining to the ballistic requirement and the laser protection requirement.

There are several optical characteristics fundamental to any lens design. These become more critical when evaluating a multiple lens system.

The primary optical effects to consider in ophthalmic lens design are power, astigmatism (cylinder), prism and magnification. These are a function of the lens thickness, curvature, index of refraction and tilt. Ophthalmic optical design is a specialized subset of optics. AOPPB has had significant experience in such design. The appropriate lens design, analysis and ray-tracing computer programs are in place.

Astigmatism, which is the difference in power between two orthogonal meridians, and prism generally will not be present for a series of lenses when viewed along a common optical axis. When any of the lenses become tilted with respect to the line of sight these effects can be generated. There are two types of tilt which may be induced into a lens in design or in use. They are "face-form" and pantoscopic tilt. The face-form angle refers to the angle of the lens with respect to the line of sight in a plan view while pantoscopic tilt refers to the deviation of the plane of the lens from the vertical in the as-worn position.

In use, the system of three lenses held by a flexible mask will be subject to variations in face-form angle and pantoscopic tilt with respect to the line of sight. This tilt will generate some astigmatism and prism. The magnitude of this effect will vary with the amount of tilt, the lens thickness and the relative curvature of the lens surfaces. Because these features are critical to producing an optically acceptable system they need to be studied during the initial design of the system.

Some of the lenses in the system may have sufficient thickness that it would be advisable to design corrected curves to yield a true zero power. This is especially true when multiple lenses are used. The initial lens designs supplied indicate that there may be a limit on the curvature of the prescription lens. This would limit the range of plus powers available.

The use of multiple lenses will cause a reduction in overall transmittance due to surface reflection losses. AOPPB will calculate the overall transmittance and show the potential benefit of the application of anti-reflection coatings.

AOPPB has extensive experience in the design of molded lenses for ballistic protection. An evaluation of all pertinent parameters will be done to best insure that the lens will meet requirements.

An evaluation will also be performed for compatibility with known methods of adding laser protection.

3.0 Specific Tasks:

The optical portion of the evaluation will consist of the following tasks:

1. Analyze the optical design for straight ahead viewing and calculate the power, astigmatism, cylinder and magnification.
2. Determine the sensitivity of each of these parameters to variation in face-form angle and pantoscopic tilt.
3. Consider the effect of a twist in the system in which one lens is at a different angle to the line of sight than the other.
4. Evaluate the cumulative error resulting in the combination of the three lenses.
5. Evaluate the range of powers that could be accommodated by the design.
6. Advise on the need for adjustment to accommodate a range of inter pupillary distances.
7. Calculate the overall luminous transmittance for the multiple lens system with and without appropriate AR coatings. This could include both photopic and scotopic transmittances and the transmittance for P43 phosphor emission for the laser protective filter if the spectral transmittance data can be provided.
8. The thickness, angular radii and attachment will be reviewed using known parameters for ballistic resistance capability.
9. The overall geometry will be evaluated for compatibility with known forms of laser protection such as molded in dyes, coated dyes, holograms and thin films.

4.0 Schedule:

The technical effort will be completed 6 weeks after task award.

5.0 Reporting Requirements:

A final report detailing the work performed and suggestions for design optimization will be furnished 8 weeks after task award.

COST SCHEDULE
BATTELLE OPTICAL STUDY

May 21, 1991

MATERIAL

TRAVEL	\$.00
MATERIAL	\$.00
	\$.00

LABOR

<u>DESCRIPTION</u>	<u>GRADE</u>	<u>RATE</u>	<u>HOURS</u>	<u>TOTAL</u>
PROGRAM MANAGER / ENGINEER	TP-8	\$29.39	80	\$2,351.20
DESIGNER / TECHNICIAN	TP-2/4	\$15.15	8	\$121.20
		TOTALS	88	\$2,472.40

TOTAL COST SCHEDULE
BATTELLE OPTICAL STUDY

May 21, 1991

MATERIAL	\$.00
LABOR	\$2,472.40
OVERHEAD @ 220.5%	\$5,451.64
	\$7,924.04
G&A @ 15.4%	\$1,220.30
	\$9,144.34
FEE @ 10.0%	\$914.43
	<hr/> <u>\$10,058.78</u>

APPENDIX E

LIST OF CANDIDATE MATERIALS FOR
COMPONENTS OF MULTI-LAYER MASK

DESIGN STATUS

O MATERIALS

OO COMPOSITES

- * - ZYTEL
- RYTON (PPS)
- PEEK
- PBT
- PET
- VECTRA
- TORLON
- ULTEM
- XYDAR

OO HOOD

- * - CQ FABRIC
- LATEX BLEND
- FLUORINATED TPE
- THIN FILM SANDWICH
- LOADED TFE
- KALREZ

OO LENS

- * - POLYCARB/SIERASIN FX (UV COAT)
- POLYCARB/GENTEX HC (SILICATE COATING)
- POLYCARB/GLASS
- POLYCARB/DIAMOND
- * - ALIPHATIC URETHANE
- TRANSPARENT EPDM

OO MULTI-LAYER FACEPIECE

- SEAL
- SILICONE
- * - KRATON
- C-FLEX
- IPN (IE. PETRARCH)
- STRUCTURE
- * - ALIPHATIC URETHANE
- EPDM
- IPN
- BARRIER
- * - FLUORO
- POLYPROP

OO FILTER

- DUPONT FABRIC
- TEXTRON FABRIC/FELT/FOAM
- * - BLUECHER FOAM
- MSA MODEL
- SBIR LOADED FILMS

MATERIAL SUPPLIERS FOR MULTI-LAYER MASK MODEL:

Material/Description	Supplier
Algicast Impression mat'l - Used to cast face impression for molds	Tri-less Sciences Inc. 1020 West Chestnut Street Burbank, California 91506 (818) 247-6910 - Carol
Dow Corning #527 Two-part dielectric gel	Brownell Electro Inc. 120 South Point Drive Bridgeville, Pennsylvania 15017 (412) 221-0074 - Joe VanAckeren
Kleen-Klay, modeling clay	Art Chemical Products 1019-T Salamonie Ave. P.O. Drawer 678 Huntington, Indiana 46750 (219) 356-2328 - Pat
Dow Corning HS RTV Silicone	Chembar Inc. 302-C Lowery Ct. P.O. Box 386 Groveport, Ohio 43125 (614) 836-5206 - Wilma
Shin-Etsu Optically clear silicone, 1 part KE 420 2 part KE 106	Medford Silicones #10 Forest Hill Dr. Medford, New Jersey 08055 (609) 953-1092 - Ted Lay
P.U.R.E. 1040 Urethane	Permaflex Mold Co. 1919 E. Livingston Ave. Columbus, Ohio 43209 (614) 252-8034 - Bob Wells
G.E. #615 RTV silicone rubber	Rudolph Brothers 960 Walnut St. Canal Winchester, Ohio 43110 (614) 833-0707 - Bonnie
USG molding plaster, hydrostone	Hamilton-Parker Co. 491 Kilbourne St. Columbus, Ohio 43215 (614) 221-6593 - Karen

Dye-keen dental stone	Riley Dental Supply 1577 Lockborne Rd. Columbus, Ohio 43207 (614) 443-3335 - Mike Riley
Castable water clear urethane, anti-foam solution, parting spray	BJB Enterprises Inc. 13912 Nautilus Rd. Garden Grove, California 92643 (714) 554-4640 - Terry McGinness
Woven filtration, "spacer" material	Pittsfield Weaving Co., Inc. Pittsfield, New Hampshire 03263 Contact: Jan Cysarz (207) 876-3485 Box 300, Guilford, Maine 04443

IMPORTANT PERSONS/COMPANIES CONTACTED

Persons/Companies Contacted:

Diving Hoods

Mar-Vel Diving Specialties

Diving Masks

U.S. Divers

Cressi-Sub

U.S. Aquasports

Hood Material

W.L. Gore and Associates, Jeff Luhnow

Tetra-Tec

Astrup

Jason Mills

Chemfab

Suspension Material

Darlington

Heat Sealers

Vertrod, Tom Sadoski, Lou Gross

Bemis

Nemeth Engineering

Model Maker

Stewart McKissick

Ben Lohrie

Optical

American Optical, Clark Grendal

Film Specialties Inc.

Lens Crafters

Select Optical

Facepiece Material

Silicones

Medford Silicones

Rudolph Brothers

Urethanes

Conap

BJB Enterprise Inc.

Moldmaking Materials

Riley Dental Supply

Chembar

Rudolph Brothers

Poly-Tek

Smooth-On Inc.

Tri-less Sciences Inc.

Brownell Electro Inc.

Art Chemical Products

Permaflex Mold Co.

Hamilton-Parker Co.

Laser Scanning

Laser Design Inc.

Filtration Spacer Material

Pittsfield Weaving

Lumite

Attachment Mechanisms

ITW Minigrip
Faceseal Materials
Bose
Brigam Medical
Deerfield Urethane
Sealmaster
Thermoformer
Thermo-Jem Plastics
Sealing Equipment
Sunbrand
Sinclair
Mid-Ohio Canvas
Hood Sewing
Super Stitches
Costume Specialties

	<u>ABBREVIATED USER RESPONSE (Mission Essential)</u>	<u>ASSIGNED CRITERIA</u>
C. Psychological Stresses	Better than current equip.	Minimize
1. Claustrophobia		Minimize
2. Distraction		
D. Physiological Stresses		90 deg. F, skin < 102 deg. F, core 135 BTU/hr removal
1. Thermal Equilibrium	No increase in casualties over 10-16 hrs. in excess of current duty uniform.	
2. Respiratory	No breathing resistance under all conditions.	30 mm H ₂ O (inhalation) 15 mm H ₂ O (exhalation)
a. Resistance		85 l/min., avg. 260 l/min., peak inhal. 300 l/min., peak exhal.
b. Flow Rate		106 l/min., 1 hr. 76 l/min., 2 hr. 48 l/min., 4 hr. 30 l/min., 8 hr.
c. Flow Volume		60 °F preferred
d. Temperature		< 10 mm Hg within external 115 mm Hg pO ₂ , lower limit
e. Oxygen Content		< 8 mm Hg if < 1 hr. < 3 mm Hg if > 1 hr.
f. CO ₂ Content		Satisfies Above
g. Dead Space Volume		< 2% body dehydration 2 l/hr. max (desert) 0.6 l/min flow minimum
3. Dehydration	No increase in casualties over 10-16 hrs. over field uniform for that environment	HEI Handbook
4. Dexterity	No worse than field uniform	
5. Discomfort	No more discomfort than standard uniform.	Minimize
a. Skin Trauma		Minimize
b. Pressure Points		
III. EQUIPMENT		
A. Physical	No larger than existing uniform plus mask.	Minimize
1. Size		Minimize
2. Weight		None
B. Consumables	Easily supplied for 72 hrs. With or without for 72 hrs.	TBD, Process Dependent
C. Power Requirements	Known levels monitored	Desired
D. Indicators		
IV. EQUIPMENT SURVIVABILITY		
A. Reliability	Meets existing regulations.	TBD
B. Decontamination	Several minutes (respiratory) 5 decon cycles/30 days (body)	AR 70-71
C. Durability	>30 days except disposables in all climatic extremes	
1. Wear/Carry		200 hrs. Functional Filter - 2 Attack, Nerve 1 Attack, Blood
2. Artificial Aging		Same, 120 hrs @ 240 °F
3. Rough Handling		Same, Q113/Mil-C-10116B
4. Adverse Environments		Functional, Mil-Std-810C
5. Storage		<-10% Degr. Mil-Std-810C
6. Packaged Rough Handling		Same as Storage

	<u>ABBREVIATED USER RESPONSE (Mission Essential)</u>	<u>ASSIGNED CRITERIA</u>
C. Psychological Stresses		
1. Claustrophobia	Better than current equip.	Minimize
2. Distraction		Minimize
D. Physiological Stresses		
1. Thermal Equilibrium	No increase in casualties over 10-16 hrs. in excess of current duty uniform.	90 deg. F, skin < 102 deg. F, core 136 BTU/hr removed
2. Respiratory	No breathing resistance under all conditions.	
a. Resistance		30 mm H ₂ O (inhalation) 16 mm H ₂ O (exhalation)
b. Flow Rate		86 l/min., avg. 260 l/min., peak inhal. 300 l/min., peak exhal.
c. Flow Volume		105 l/min., 1 hr. 76 l/min., 2 hr. 48 l/min., 4 hr. 30 l/min., 8 hr.
d. Temperature		60 °F preferred
e. Oxygen Content		< 10 mm Hg within external 116 mm Hg pO ₂ , lower limit
f. CO ₂ Content		< 8 mm Hg if < 1 hr. < 3 mm Hg if > 1 hr.
g. Dead Space Volume		Satisfies Above
3. Dehydration	No increase in casualties over 10-16 hrs. over field uniform for that environment	< 2% body dehydration 2 l/hr. max (desert) 0.5 l/min flow minimum
4. Dexterity	No worse than field uniform	MIL Handbook
5. Discomfort	No more discomfort than standard uniform.	Minimize
a. Skin Trauma		Minimize
b. Pressure Points		
III. EQUIPMENT		
A. Physical		
1. Size	No larger than existing uniform plus mask.	Minimize
2. Weight		Minimize
B. Consumables	Easily supplied for 72 hrs.	None
C. Power Requirements	With or without for 72 hrs.	TBD, Process Dependent
D. Indicators	Known levels monitored	Desired
IV. EQUIPMENT SURVIVABILITY		
A. Reliability	Meets existing regulations.	TBD
B. Decontamination	Several minutes (respiratory) 5 decon cycles/30 days (body)	AR 70-71
C. Durability	>30 days except disposables in all climatic extremes	
1. Wear/Carry		200 hrs, Functional Filter - 2 Attack, Nerve 1 Attack, Blood
2. Artificial Aging		Same, 120 hrs @ 240 F
3. Rough Handling		Same, Q113/Mil-C-10116B
4. Adverse Environments		Functional, Mil-Std-810C
5. Storage		<=10% Degrad, Mil-Std-810C
6. Packaged Rough Handling		Same as Storage

	<u>ABBREVIATED USER RESPONSE (Mission Essential)</u>	<u>ASSIGNED CRITERIA</u>
D. Hardness	5 decon cycles/30 days	AR 70-71
E. Availability	Close to 100%	100%
F. Maintainability	Soldier maintainable	100% or Discard
G. Cleanability	Soldier cleanable	100% or Discard
V. USER SUSTAINABILITY		
A. Drinking Flow Rate	Uncontaminated water with one hand in all conditions.	1 Qt/10 min., 2 min prep. 0.6 l/min. desired
B. Feeding	Capability to ingest suff. calories or nourishment.	10 hr. provisions
C. Waste Disposal	Solid and liquid disposal	100%
D. Accessibility to Medical Treatment	Immediate first aid admin.	100%
VI. OPERATIONAL PARAMETERS		
A. Environmental Conditions		
1. Natural/Climatic	Functional in all climatic extremes with one or more designs	
a. Operational		-25 F - 120 F
b. Storage		-60 F - 160 F
2. Thermal/Blast	AR70-71; Non-flammable	AR 70-71
3. Altitude	45,000 feet, Valsalve	No O ₂ Required (Demand)
4. Competitive Contaminants	Functional	<= 10% degrad. built in
5. Electric Shock	Non-static, EMI approved	Insulated, EMI protected
B. Equipment Compatibility	Compatible with mission essential equipment	100% Compatibile (end. 1)
C. Exit/Entry	Doff unassisted without contamination transfer	100% Compatible
D. Countersurveillance	No increase in awareness	No increase
VII. LOGISTIC SUPPORTABILITY		
A. Field Support	Minimal	100% Replace or Discard
B. Storage/Shelf Life		
1. Unit/Individual	>30 days	1 yr.
2. Depot	10 years packaged	10 yrs.
C. Special Tools	No special tools	None
D. Special Training	Entry level only, No MOS	None
E. Test Equipment	No special equipment	None

SUPPLEMENTARY

INFORMATION

AD-A253 392

(2)

DTIC
ELECTE
JUL 23 1992
S C D

REPORT

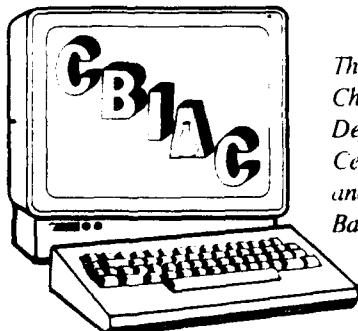
Evaluation of Multi-
Layer Mask Concept
for Respo 21

92-21
Missing Pages

1, 3, 4, 5

To
U.S. Army Chemical Research,
Development and Engineering Center

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited



The Chemical Warfare/
Chemical and Biological
Defense Information Analysis
Center is a DoD information
analysis center operated by
Battelle Memorial Institute

DECEMBER 1991

Battelle
Putting Technology To Work

92-19383



92 7 21 058

EVALUATION OF MULTI-LAYER MASK CONCEPT FOR RESPO 21

1.0 BACKGROUND

The Chemical Research, Development, and Engineering Center (CRDEC) is entering the development of the next generation of respiratory protection (RESPO 21) to replace the current M40 series of protective masks. One of the system concepts is a multi-layer protective mask which utilizes a series of layers to optimize material properties for both sealing and chemical agent protection.

As part of the RESPO 21 program, this task was conducted to integrate the results of previous studies and to evaluate methods for optimizing the functional characteristics of a multi-layer mask system concept. For example, some of the results from the previous studies include advanced seal design, seal attachment systems, electronics, filtration analyses, optics, and materials surveys. These studies provided a basis to begin design of a demonstrator model of a multi-layer mask concept. The desired performance of the developed multi-layer mask was specified in the form of requirements generated by CRDEC. The ability of the demonstrator model multi-layer mask to fulfil these requirements established the functional characteristics for the multi-layer mask concept. In the process of developing a more functional model, methods were evaluated to optimize the functional characteristics.

1.1 Objective

The objective of this program was to evaluate the feasibility of a multi-layer system concept for RESPO 21. Demonstrator models were fabricated to facilitate the evaluation.

1.2 Program Plan

In order to meet this objective, this program was conducted through a series of tasks. First, design goals were established, followed by review of the previous work, and a definition of the desired functional characteristics. The design of the multi-layer mask was developed. Once the design was ready, techniques were evaluated for fabrication of the mask. The mask prototype was fabricated, tested, and evaluated. Modifications were then made to the design

The requirements for the M40 mask are less stringent than the Draft RESPO 21 requirements but they are included in this report as a reference to show the capabilities of the current respiratory protection system. It was desirable to configure the multi-layer mask for RESPO 21 to meet or exceed the M40 mask requirements. The M40 mask requirements indicate what is currently possible with previous technology and thus provides the baseline design criteria for the multi-layer mask development.

The previous design efforts provided valuable background information for several of the components for the multi-layer mask. Information from these efforts helped facilitate the design, function and configuration of the multi-layer mask and related components. A list of the previous design efforts is included in the Bibliography in Appendix B.

The patent disclosure for the multi-layer protective mask prepared by CRDEC at CRDEC provided additional insight as to the configuration and intended design features of the mask. The patent disclosure also highlighted performance specifications with comparisons to the M40 mask. The patent disclosure on the multi-layer mask is in Appendix B.

In addition to the draft requirements, the M40 requirements, and the patent disclosure, Battelle was provided with several documents and reports generated for and in some cases obtained by CRDEC. These documents were relevant to the multi-layer mask development and is listed in Appendix B:

4.0 DEFINE FUNCTIONAL CHARACTERISTICS

After studying and reviewing the background information available, Battelle identified the functional characteristics that would guide the development of the multi-layer mask demonstrator model. These functional characteristics included: comfort, fit, ease-of-use, agent resistance, decontaminant resistance, visual capabilities, respiratory load, thermal burden, and protection. The functional characteristics pertaining to each of the individual components comprising the multi-layer mask are described in the following paragraphs.

4.1 Facepiece

The facepiece, besides providing protection to the wearer and support for the lenses, check valves, and other components, was required to be made of an optically clear elastomeric material. The facepiece was also to be low in profile, flexible, and light in weight.

4.6 Hood

The hood will be attached to the peripheral edge of the facepiece. The hood provides protection from liquid chemical agent to the top and back of the head, and the shoulder area. The hood is attached to or part of a bib assembly which supports the filtration system as well as all of the electrical components.

4.7 Filter Element

The filter element will be located on the front of the bib and connected to the facepiece via tubes and/or air lines. The filter element is to be a replaceable item.

4.8 Communications

The intelligibility of speech while wearing the multi-layer mask should be improved over the M40 masks. The communications system should include a microphone placed inside the mask and an amplifier/speaker unit mounted on the outside.

4.9 Blower

The blower provides a constant flow of filtered air through the facepiece. In addition, a blower also provides a mild form of convective cooling to the user as well as providing the user with a psychological advantage which enhances confidence in the protective ensemble.

4.10 Power Supply

The power supply should provide all of the power required to operate the blower and the communication system for a minimum of six hours.

5.0 DESIGN

Based on these functional characteristics, the multi-layer mask design could begin.